THE AIR

AND ITS MYSTERIES

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THE AIR AND ITS MYSTERIES

BY

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WITH A FOREWORD BY

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Foreword

Books on scientific subjects intended for general readers vary greatly in scope and character, but the purpose of all of them is to create or extend interest in the realm of natural knowledge. One group is of the transformer type – to use an electrical simile – and serves to reduce the high tension currents of such philosophic conceptions as relativity and wave-mechanics to a potential which will illuminate a mind of moderate intelligence. However transcendental the ideas involved, whether in the movements of atomic nuclei or the expansion of the universe, it is gratifying to be assured by the large sales of works devoted to their interpretation that many members of the general public find pleasure in the mental exercise of understanding them.

Before, however, any works of this type can be rightly comprehended, it is necessary to be acquainted with the main facts relating to the natural events and phenomena with which they are concerned. Books which deal descriptively with such matters belong, therefore, to a different group from that of those devoted to the more speculative aspects of scientific progress. They record the methods and results of observation and experiment by which natural knowledge is advanced and principles established for the practical service and intellectual expansion of mankind.

Miss Botley's book falls into this category, and is a

remarkably good example of it. Though in Great Britain the weather is a never-failing topic with which to open a conversation, the lack of knowledge concerning the conditions which modify it, or of the ocean of air in which we live and have our being, usually becomes obvious after the customary exchange of salutations. Weather prophets who have the temerity to predict conditions weeks, months, or years in advance are, on this account, commonly considered to be just as trustworthy as scientific meteorologists who, in these islands, are rarely able to justify forecasts more than a day or two ahead, much as they would like to do so.

Miss Botley does not, however, limit her work to this practical, but nevertheless incidental, application of meteorological science to everyday life. She shows how knowledge of the upper air, acquired purely in the pursuit of scientific truth, laid the foundations of the intricate structure now becoming familiar to aviators. She traces the growth of the highways of the air and of flight along them, and her story of this and other achievements has always the human touch which saves it from being placed in the obviously instructional class of simplified text-book to which many adult readers object. The atmosphere of the earth, and what it signifies to human life and activities, has been dealt with in a fair number of books from various points of view, but I know of none of the size and style of this small volume which brings together existing knowledge relating to it more successfully than has been accomplished by the author.

Several years ago the Washington Academy of Sciences published a list of one hundred books on scientific subjects; and in the preparation of the list

two tests were used as principles of selection. One was: Would the average reader who uses a public library, after beginning to read the book in question, read it through to the end and come back to the librarian for another on the same subject? The second test was that the book should have been written by an author who understood the subject thoroughly, and it should not be so old as to be obsolete in the facts and speculations. There are to-day many books on scientific subjects which would pass these tests, but in its particular field, and for the public for which the book has been written, *The Air and its Mysteries* is worthy of taking a high place among them.

R. A. Gregory

Preface

The nature and scope of this book are, it is hoped, sufficiently and clearly indicated by its title. It is in no sense a text-book, but an attempt to give those who live in an air-minded age some insight into the new and wonderful realm of which, through the courage of the pioneer and the skill of the scientist, they have been made free. And it is also hoped that those who do not feel the call of the air in the way that some do may yet find something of interest in the following pages.

One of the greatest achievements of science during the present century has been the slow unveiling of some of the secrcts of the atmosphere. Knowledge has come from various sources: thus the discovery of radio opened the way to that of the ionosphere, and aviation and the ascents of Mount Everest have led to increased appreciation of the atmosphere in its rôle as sustainer of life.

Unfortunately, a large proportion of this new and fascinating lore has remained buried in the pages of specialist periodicals from which it has been my pleasant task to extract it and reproduce it in a form which, it is my earnest hope, may serve to entertain all who have any interest in the world about them.

My special thanks are due to:

The President and Council of the Royal Meteorological Society for permission to reproduce the extracts given from the Quarterly Journal of the Society, and

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CICELY M. BOTLEY

Hastings,
Easter 1938.

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CHAPTER I

The Ocean of Air

'This most excellent canopy, the air'

Hamlet, II. 2

In the old parish church of Winchelsea in Sussex there are three very beautiful stained glass windows which were put up in honour of the men from the five historic towns of Hastings, Romney, Hythe, Dover, and Sandwich – the famous Cinque Ports – and their equally historic associates, the 'ancient towns' of Rye and Winchelsea, who died in the Great War, and in thanksgiving for those who came back to their homes and friends in safety. There are other handsome coloured windows in this church, and it is a wonderful experience to go into the dark building on a bright summer's day; it is like entering a casket of jewels. But, though the other windows are both beautiful and striking in their colours and designs, they are not interesting as are these three war memorial ones, for they depict the artist's idea of the three great realms of nature, the Land, the Ocean of Water, and the Ocean of Air.

For the world in which we live is made up of a solid core or centre and two wrappings or envelopes. The solid part, of course, makes up the land, and goes on under the first wrapping which is the ocean of water or the sea. If all the sea were dried up, there would be

great hollows left which would represent the ocean beds, and from these beds mountains would rise up where islands used to be. The second wrapping, the air or atmosphere, is not found in the hollows of the land, but swathes earth and sea completely round, and men and animals and birds move about in it as the fishes move about in the sea.

The atmosphere pervades everything and is found everywhere. It fills things that we usually call 'empty.' Bottles and boxes, unless they have been exhausted under an air pump, are full of air, though, as it is colourless and invisible, it cannot be seen. We can go nowhere and not find air; we may go exploring to the Poles, or take the air mail to Equatorial Africa; we may go down the deepest mine at Johannesburg or climb to the top of Mount Everest; we may go up into the stratosphere with Professor Piccard, but still we shall find air. And the records from the little unmanned balloons sent up by weather experts, the flashing shooting stars and the waving draperies of the aurora, tell us that the air goes on and on, how far no one can really say, except that it is at least 625 miles above our heads. Indeed, it is likely that the air does not come to a definite end like the sea does; it probably thins out very, very gradually, so that there is no place where one could say, 'Here is air' and 'there is empty space,' in the same way that one can say, 'Here is water and there is land.'

For the air is quite different from either the sea or the land. It is as material as they are, but with a difference.

The land is a *solid*, which means that the particles or molecules of which it is made up are packed so tightly together that only with great trouble can they be

forced apart, and which also means that a solid has a definite shape and boundaries.

The sea is a *liquid*, which means that, though the molecules are clinging together, they are doing so not so tightly as they would in the case of a solid, so that, although a liquid has a definite boundary, it can spread all over the place.

The air is a *gas*, which means that the molecules are not held together at all, but spread themselves over as large a space as possible. Half a pint of water put into a pint jug would only fill half the jug, but half a pint of air or other gas would spread itself out and fill the whole jug.

But if the air is a gas, and gases spread themselves out as much as they can, why has the Earth been able to keep this thick ocean of air wrapped round her for the millions and millions of years she has lasted? Because the gases in the atmosphere do not have it all their own way, the molecules may be very lively, and keep on moving about as they do at great speeds, but they are not lively enough to prevent the earth pulling them to her by that wonderful force called gravitation, the same force that makes things fall to the ground, and that keeps the Earth and all the other planets going round the sun instead of flying about space anyhow. To get right away from the Earth, the molecules of air would have to get up a speed of seven miles a second, and that does not often happen, so the Earth has kept her air wrapped tightly round her.

On the other hand, the Moon is so small, and her gravitational pull is so weak, that a molecule of air would only have to get up a speed of 1½ miles a second to get right away into space, and air molecules often go

as fast as that. So the Moon has never had any air (or was never able to keep any atmosphere that she had in the beginning), and is a dead world, a mere lump of rock; and the same seems to be true of the planet Mercury, which can sometimes be seen at sunset. He is a little bigger than the Moon, but not big enough to keep an atmosphere. The red planet Mars, however, which is twice the size of the Moon, has a very thin covering of air, so thin it is thought that a barometer on Mars, instead of usually standing at 30 inches, as it does on Earth, would stand at 3 inches, showing that the pressure of the Martian atmosphere is only one-tenth that of ours. On the other hand, the planet Venus, which is about the same size as the Earth, has a dense atmosphere, and that is why she is so bright and beautiful, for the light that comes from her is reflected, not from volcanic ash which seems to cover the Moon, but from the top of a layer of clouds. Once Venus and Mercury were seen together in the same field of the telescope, and the difference in the light coming from the dull rock of Mercury and the bright clouds of Venus made the latter look like silver and the former like zinc or lead. And, needless to say, the four giant planets, Jupiter, Saturn, Uranus, and Neptune, have immense atmospheres of gas, though very different from the air of Earth.

Now since the air is a material thing it must have weight. The first scientist to prove this was Galileo (1564–1642), and it was his pupil, Torricelli, who devised the first barometer. He had proved that water could not rise more than 32 feet in a simple pump because the pressure of the air on the water in the well could not support the weight of a higher column,

and, following the reasoning of his master Galileo, he argued that if the pressure of the air supported that length of water it should support lesser lengths of heavier substances; for instance, an equivalent column of quicksilver or mercury, which weighs thirteen times

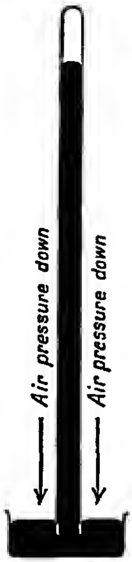


Fig. 1. Mercury Barometer

as much as water, should only be about 30 inches high.

Except in matters of detail, the mercury barometer has remained unchanged since Torricelli's day. It consists of a glass tube, open at one end and about four feet in length, which is completely filled with mercury, and inverted in a cistern of mercury.

The space above the mercury is quite empty, and is usually called the Torricellian vacuum. Mercury

barometers are used for all accurate scientific work, but travellers generally carry a much lighter and more convenient instrument, which is called an aneroid barometer. It is made of one or more air-tight boxes, the top of which is a thin sheet of metal which bends slightly as the pressure of the air changes. This motion is much magnified by a number of levers which make a hand move over a dial, or, as in the case of the barographs which are so commonly displayed in opticians' shop windows, the levers move a pen over a chart fixed on a drum which is usually set to revolve once in a week. These barographs are very useful for keeping a permanent record of the changes of pressure, for the weight of air over a particular place is always changing. This fact was discovered by Torricelli, and was one of the reasons why the new instrument became so popular, for it was soon noticed that the mercury usually rose before fine weather and sank before storms. It was not long after Torricelli's discovery that Dr. Hooke, in this country, not only made several improvements in the instrument, but made a plan for forecasting the weather from its readings.

There are some amusing stories told about the early days of barometers. A Mr. David Gregory, who possessed the first barometer in Scotland, nearly got into serious trouble because of it; his knowledge of the weather was so great that the superstitious people thought he must be a wizard, and only his great kindness to the poor prevented his being arrested and brought to trial for witchcraft. Similarly, the people of Magdeburg, in Germany, were very suspicious about a water barometer which Otto von Guericke, the learned but eccentric mayor, had put up with its

top projecting from the roof of his house, and which had a wooden doll floating on the top of the water. As a water barometer is 13 times as long as a mercury one, the excursions of the column of water are correspondingly great, so the doll used to disappear out of sight when the weather was stormy and pop up again when the weather was fine.

Another discovery which was soon made when Torricelli's researches were made known was that the height of the barometer was less the higher one went above sea-level. Pascal, the famous French scientist and philosopher, asked his brother-in-law to repeat Torricelli's experiment on the top of the Puy-de-Dôme, a mountain in Southern France 3,000 feet high, and it was found that the mercury column stood three inches lower than it did at the foot of the mountain. This is the method used by explorers to ascertain the height of mountains: they compare the readings of the barometer they carry with that of another instrument at a place of which the height is known. Some of the modern instruments are so delicate that they can show the difference in pressure between the floor and the top of a table. The altimeters carried by aircraft are really aneroid barometers.

The variation of pressure with height is strikingly illustrated by Fig. 2, which shows the trace of an ordinary barograph during a motor run from Cornwall to London. The peaks on the record (millibar scale) are due to the various river valleys (Fal, Tamar, Exe, etc.) crossed, while the depressions indicate as clearly the passage over Bodmin Moor, Dartmoor, the Blackdown and Mendip Hills, and Salisbury Plain. This record also brings home the necessity for reducing to

some common level the readings of all barometers before they can be used for a scientific purpose such as weather forecasting. The standard generally adopted is that of the mean level of the sea (M.S L.).

Consideration of this record also shows how misleading the legends usually affixed to barometers can

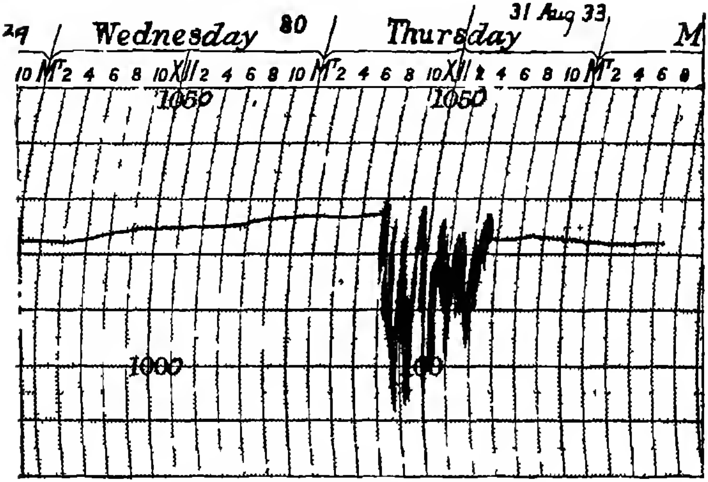


Fig 2. Barograph of motor journey.
(*Q. J R. Meteor. Soc*, Oct, 1937)

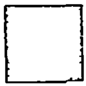
be. An instrument which stood at 'Set Fair' at Truro might point in the direction of 'Change' on Bodmin Moor, though the weather was the same at both places !

The change of pressure with height also affects the boiling-point of water. The lower the pressure above the surface of the liquid the less is the energy required to turn it into vapour. Thus Darwin, during his journey in the Cordillera of South America, camped at

a place 11,000 feet high, where the water boiled at so low a temperature that the potatoes for breakfast, 'after remaining for some hours in the boiling water, were nearly as hard as ever. The pot was left on the fire all night, and next morning it was boiled again, but yet the potatoes were not cooked. I found out this by overhearing my two companions discussing the cause; they had come to the simple conclusion that "the cursed pot" (which was a new one) "did not choose to boil potatoes." '

For over two hundred years after the time of Torricelli barometers were graduated in inches, and the pressure of the air was given in terms of the length of the column of mercury supported by the air. Thus a reading of '30 inches' would be talked of in the British Empire and America, and '760 millimetres' in the other countries of the world, which use the metric system. But about 20 years ago scientists began to think it would be a good thing to have a measurement which would be understood all over the world, and which would be a measurement of weight. After all, since it was the weight of the air which was being measured, it was rather inconsistent to talk of it in terms of length; it would be like asking for a yard of butter rather than for a pound. So, after a good deal of discussion, the millibar was introduced and is used in all scientific work. It is a measure based on the C.G.S. system, which is an abbreviation for centimetre, gram, second. It is a system of units universally used by scientists for measurements, and based on the centimetre for length, the gram for weight, and the second for time. The unit of force in this system is the dyne, which represents the force which, applied to a mass of

one gram for one second, will give it an acceleration of one centimetre per second. The millibar equals 1,000 dynes per square centimetre. At the time of writing, the barometer is reading about 1,007 millibars, so the force pressing on the square centimetre of paper shown here can be easily worked out. The lowest



Square Centimetre

atmospheric pressure ever measured (886.8 mb.) was on board ship on August 18th, 1927, during a tropical hurricane, 400 miles east of Luzon in the Philippines. Some of the highest pressures known occur in Siberia in winter.

But perhaps the pressure of the air can be better appreciated when it is given in English measurements, as 15 pounds on every square inch, which is about the area of a two-shilling piece. This means that the pressure of the air on the body of a grown man is about 15 tons; and yet we are quite unconscious of the weight, because, as we are made to live in the air, the gases and fluids inside the body press outwards with just the same force as the air outside presses inwards. It is this fact that has been used in the machine called the 'iron lung,' which has saved so many lives since it was invented by Dr. Drinker of Harvard College in 1928. In a healthy human being the air inside the body is at the same pressure as that outside it, but when the muscles of the chest are paralysed by disease or poison, this balance is upset. The 'iron lung' is a machine which, by altering the air pressure directly outside the

chest, simulates natural breathing. It consists of a chamber, in which the patient is placed. In one wall there is an opening through which the sick man's head protrudes. There is a small pump driven by an electric motor which exhausts the air in the chamber, and the patient's chest expands as the air in the room outside enters through the mouth and nose. Then, by means of a valve, air is admitted to the machine, and the increased weight on the chest causes him to breathe out, and the process is repeated, the machine being regulated, not only to the patient's natural rate of breathing, but to the depth of respiration as well.

There are many interesting and simple experiments which show the reality of the pressure of the air. A very instructive one is to take an ordinary tin can and partly fill it with water. The water is boiled for some time, so that the air in the can is driven out, and nothing left above the water but steam. Then the can is tightly corked and put in a sink or tray, and cold water poured over it. The cold turns the steam inside the can into liquid water, which of course takes up much less room than the vapour. The air having been driven out by boiling, the top of the can is now empty, and the weight of the air outside will crush the can in.

Another interesting experiment, which shows how the air presses round on every side, is to take a tumbler, and fill or partly fill it with water. Then a piece of writing-paper or card is put over the top, and, while care is taken to keep the paper firmly pressed against the glass, the tumbler is turned over. The hand may be taken away but the paper will not fall, as it is kept in its place by the upward pressure of the air.

The pressure of the air and its changes have many

interesting and important results. It plays a great part in breathing, and the difficulties encountered by climbers on high mountains are largely due to the decreased pressure. The amount of oxygen taken up by the blood circulating through the lungs depends directly upon the pressure at which the gas is delivered to the blood – the lower the pressure, the less oxygen the blood can take up to carry to the tissues all over the body – so that when the pressure of oxygen in the

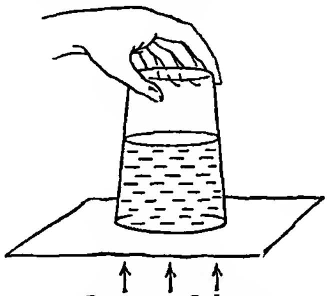


Fig. 3. Experiment showing pressure of atmosphere

breathed air is reduced below certain limits, various bodily symptoms are experienced. For instance, if an airman rapidly ascends to a great height he may lose consciousness without warning. In 1875 the French scientist Tissandier went up in a balloon, and reached a height of at least 26,500 feet. Tissandier fainted, and when he came to himself the balloon was descending, and his two companions were dead. It has been thought that the same sort of accident might happen to climbers on Mount Everest, but the medical opinion is that such a misfortune would not be likely, as, owing to climbing being a much slower business

than going up in a balloon or aeroplane, the reduction of pressure would be much more gradual. The danger would be of a much more subtle character, for the mind and the senses would become dulled without the climber knowing that anything was wrong; he would become what has been graphically termed 'baby-minded.' He might see a dangerous storm approaching and not realise his peril, or he might know that he was in danger and be unable to decide upon a course of action that would enable him to escape. For these reasons many doctors think that Mount Everest will never be conquered without the aid of oxygen equip-

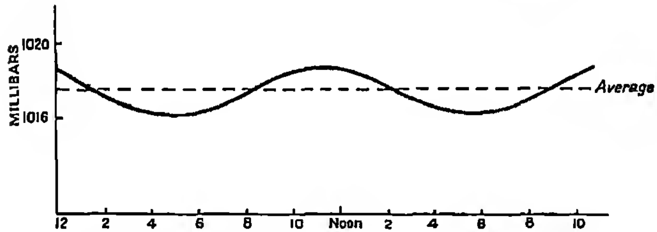


Fig. 4. Typical tropical barogram. (Much enlarged)

ment which delivers the gas to the lungs at the right pressure.

The pressure of the air changes rhythmically throughout the day. In this part of the world the changes are masked by the irregular changes brought about by the passing of storms and so on, but in the tropics the daily variation of the barometer may be traced on barograph charts for weeks on end; indeed, the barometer is almost as good as a clock, standing highest at 10 a.m. and 10 p.m. and lowest at 4 a.m. and 4 p.m. This regularity has one great advantage:

often the first warning of the approach of those very destructive and violent storms known as hurricanes is that the regular daily rise of pressure does not take place.

There is also a tide in the atmosphere caused by the moon, but the daily changes in pressure produced are so slight as to be negligible for ordinary purposes.

The various irregular changes of pressure brought about by the passage of weather systems also have some very interesting results. Some years ago, one day in July, the newspapers came out with headlines like these:

TIDAL WAVE TRAGEDY

BOATS ENGULFED IN HUGE WALL OF WATER

THRILLING RESCUE SCENES

which headlines had reference to the exciting scenes that took place when, on the evening of July 20th, 1929, a huge wave suddenly rose out of the sea, and swamped the coast round the south-east of England. What happened at Hastings is typical: 'An immense bank of water, estimated to be 20 feet high, mounted from a calm sea and rushed towards the shore with incredible speed. It was dead low tide at the time, and the wave tore up the almost deserted beach for a distance of nearly 50 yards. . . . The wave receded as rapidly as it had advanced, leaving a handful of onlookers gasping with astonishment.'

The cause of all this excitement was a sudden change in the pressure of the air, due to the passage of a line-squall across the English Channel, which meant there was a sudden rise of pressure along a line parallel with the coast, which line of extra pressure travelled

steadily across the sea. Thus, first of all the sea-level was depressed somewhat by the extra load of air above it, and then raised again as the extra pressure was lifted. This set up a wave, which became much bigger when it entered the shallow water near the land, so that when it reached the shore it ran inland for some distance.

Now, country people have always said that streams rise before storms, and the records from the special gauges set up by engineers to measure the flow of water in streams and rivers show that sometimes this saying is true – that there is occasionally an increase in the flow of streams when the barometer falls quickly. This is probably caused by the underground water which feeds the streams rising a little when the pressure of the air above it is lessened.

In many parts of the world there are what are called 'blow wells,' which are wells in which large quantities of air are discharged, often with loud groanings and whistlings, through the water, immediately before a storm, when the pressure is falling. There are several in France in the district round Le Havre, and the country people use them as barometers. In the Forest of Fontainebleau, too, there is a cesspool full of gravel, which blows so strongly when bad weather is about that the mud and water it contains are thrown out and discolour the surrounding grass.

This decrease in the pressure of the air in bad weather is also the reason why ditches and drains smell before storms, since the lowered pressure allows the foul gases to escape more easily.

It has also been noticed that earthquakes often happen at the same time as bad storms like the hurricanes of the West Indies, in which the pressure falls

very low at the eentre, and whieh are eomparatively small in size, besides being on the move the whole time. This means that the same plaee may experienee, first, the removal of several thousand million tons of air, and then have the same weight put back again, all within, say, thirty hours. It also means that the weight of air over the land outside the storm is very different from that at the storm eentre, two hundred miles, or even less, away. In a steady part of the world like England, sueh shifting of weight might not matter, but in regions like the West Indies, which do not seem to have settled down in the geological sense, sueh a taking on and off of all these millions of tons of air might be the last straw, and eause those strains and slips in the earth's erust which give rise to earthquakes.

The storms in which the greatest reduetion of pressure takes plaee are those very small but intense disturbances known as tornadoes, or whirlwinds. The fall of pressure in a tornado has never been measured direetly (probably no instrument would survive the experience), but that it must be very great is shown by the faet that the sea rises about eight feet under a waterspout (whieh is a tornado taking place over the sea or river) and by the nature of the damage done. Corks are driven out of bottles, ehickens stripped of their feathers, whieh seem to be torn from the body by the expansion of the air in the quills. Not so long ago a tornado passed over Malta, and ripped the roofs off two hangars, and the men at work in the buildings at the time said they felt their eardrums being blown out. The reduetion of pressure as the tornado passed was too sudden and too momentary for the Eustaehian tube, whieh runs from the back of the mouth to the middle

ear, to fulfil its function of equalising the pressures on both sides of the eardrum.

And what is the total weight of the air? If an upright tube were placed over a square inch of the earth's surface, extending to the top of the atmosphere, the air contained in it would weigh about 15 pounds. From this it can be calculated that the whole mass of the atmosphere weighs between five and six thousand million million tons, or enough to give every man, woman, and child in the world about three million tons each! So it can be seen that, despite such sayings as 'as light as air,' the atmosphere is far from being an 'airy nothing'!

And whence came this vast mantle of gas wrapped round the world? Here the window at Winchelsea, with its whirling spheres showing the mystery of creation, gives a hint. Though no human soul will ever know what really happened when this earth was born, there are those who venture to make guesses. Prominent among these is Dr. H. Jeffreys of Cambridge, who points out that when the world was very young, and therefore very hot, the molecules of the light gases that make up the atmosphere would move so fast that they could not be held by gravitation, but would slip away into space. Therefore, says Dr. Jeffreys, the atmosphere, as we know it to-day, came from chemical changes in the rocks, but as to details, that is another question.

CHAPTER II

Air, the Breath of Life

'And 'tis my faith that every flower,
Enjoys the air it breathes'

WORDSWORTH

There has probably been no time, since man began to think at all, that the absolute necessity of the air for life has not been recognised. No doubt some such idea was in the minds of the Greek philosophers when they named air as one of the four elements out of which everything was made; indeed, Anaximenes regarded it as the primal substance out of which all matter was condensed.

It is commonly held that the first scientist to prove that air was not an elementary substance, but a mixture of gases, was Scheele, who, in 1772, showed that it contained at least two gases, which he called 'fire air' and 'foul air.' However, recent researches amongst the private papers of that extraordinary son of the Renaissance, Leonardo da Vinci (1452–1519), shows that he had satisfied himself that air has two components, one of which is used up in burning, leaving a second behind which does not support life. But, as the Italian did not publish his discovery, the world had to wait another two centuries or so for the unveiling by Scheele and his contemporaries of one of the greatest mysteries of the air – its relation to life.

The first accurate analysis of air was performed by Cavendish in 1781, and his figures, given in the table against the results of one made in 1937, show how carefully his work was done, especially when it is remembered that he was unaware of the existence of the carbon dioxide and the inert gases. The figures are:

	Cavendish	Modern (*Q.J.R. Meteor. Soc.*, 1937)
	per cent	*per cent*
Oxygen	20·83	20·95
Nitrogen	79·17	78·09
Carbon dioxide		·04
Inert gases		·94
Water		Variable
Dust		Variable

All these gases are so intimately mixed together that they behave in many respects as if they were one uniform gas. If the air were perfectly still, it is likely that the various gases would separate out according to their weights, like milk and cream, but in nature this is prevented by the constant churning action of air currents, so that, save for slight local differences, the composition of the atmosphere is much the same all over the world. High up in the stratosphere there is a slight diminution in the amount of oxygen. As regards the upper atmosphere very little is known, but, as will be mentioned in a later chapter, observations of the aurora suggest that the oxygen-nitrogen mixture prevails.

The pioneer experiments of Leonardo, and the later researches of Scheele and others, showed that one of the principal constituents of air was essential both for life and for burning. Scheele called it 'fire air,' but it

is now called oxygen. This name, which means 'acid generator,' was given it by the great French chemist Lavoisier, because he believed it to be an essential part of every acid. This idea has been found to be untrue, but the name has stuck.

Oxygen is a colourless, tasteless gas. One of its chief characteristics is its great chemical activity, which renders it capable of entering into combination with most substances. This combination can take place at different rates. Sometimes, as in the rusting of iron, the process is so slow that no heat is given out; at other times, as when the same iron is made to burn in pure oxygen, the rapidity of the combination produces light and heat; and sometimes heat is produced and no light, as when the combination goes on at a steady rate and is spread out over a large space. This is the case in the human body. The phrase 'the fire of life' is no literary flourish. The material basis of animal life is really nothing but the combination of oxygen with the tissues. That is one reason for taking food – to replace the carbon, hydrogen, and nitrogen that are continually being burned to carbon dioxide, water, and urea, in the same way that fresh supplies of coal-gas are needed to replace that which is being burned to carbon dioxide and water in a household gas-fire. Only, as life is more complicated than a gas-stove, the arrangements for feeding the living flame are infinitely complex. Indeed, the bodily arrangements and adjustments required to serve the needs of such highly developed organisms as ourselves are so amazingly complicated and delicate that one has to cry with Hamlet, 'What a piece of work is man!'

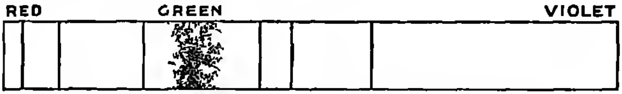
During breathing, the air is drawn in by way of the

nose and throat into the windpipe, which, at its base, divides into the two bronchi, each of which goes to a lung. A large portion of each lung is taken up with the branches of the bronchi, and the tiny air-cells in which they terminate, and which are so numerous that, despite their small size, they have, it has been calculated, a total surface in each lung of 1,000 square feet. Over the whole surface of these air-cells is a close mesh of minute blood-vessels, the blood in which is only separated from the air in the cells by the finest of membranes. There is a difference in pressure between the oxygen in the air-cells and the carbon dioxide in the blood, so diffusion takes place, carbon dioxide passing into the lungs to be breathed out, while oxygen passes into the blood and is carried to where it is needed. In the tissues the reverse process takes place – the blood gives up its oxygen and takes up carbon dioxide. And so the cycle goes on; from the moment that the first cry of a new-born child announces that it has drawn its first breath, through all the years of perhaps a long life, a ceaseless stream of blood is being pumped by the heart through the network of lung capillaries, and that marvellous army of red corpuscles is busy loading oxygen and dumping carbon dioxide.

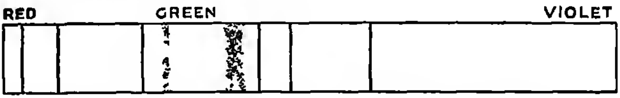
Many are the marvellous things to be found in nature. Everyone can make their own list, but surely the red blood corpuscles would come high up on each one. They are so small that the size in figures means little, yet they are so numerous that it has been estimated that their combined surfaces equal 9,000 square yards per person. At high altitudes, where the pressure in the lungs is so diminished that they cannot

take up a full load of oxygen, they multiply in number. The last stage of the journey to Mount Everest runs for 200 miles across relatively level country at a height of over 13,000 feet. During the 1936 expedition it was found that during this part of the route the climbers had become acclimatised; the number of red corpuscles had increased 20 per cent, and they arrived at the Base Camp, 16,000 feet, feeling perfectly fit.

The red corpuscles owe both their power of carrying



(*a*) Absorption spectrum of reduced hæmoglobin without oxygen in venous blood.



(*b*) Absorption spectrum of oxygenated hæmoglobin in arterial blood.

Fig. 5

oxygen and their colour to hæmoglobin. This is rather a complicated substance made up of carbon, hydrogen, oxygen, nitrogen, and iron, which has the property of combining loosely with oxygen at the pressure under which it is in the lungs and giving it up at the lower pressure which exists in the tissues. When by itself it is purple in colour, and gives an absorption spectrum[1] showing a broad dark band in the green (Fig. 5*a*). It is this 'reduced' hæmoglobin that

[1] Absorption spectra of this type are obtained by placing a glass cell containing the liquid to be examined between the spectroscope and a source of light. The rainbow streak is then seen to be crossed by a number of dark bands that vary with the particular substance under examination.

gives veins their characteristic blue tint. Sir Joseph Barcroft found that the faces of the inhabitants of the high-level villages in the Andes were plum-coloured, because the individual corpuscles could not take up enough oxygen to change the purple reduced hæmoglobin into the red oxyhæmoglobin. At sea-level, however, the change is complete; on entering the lung capillaries the blood becomes oxygenated, and for the time being the hæmoglobin is transformed into oxyhæmoglobin. This is a red compound that gives the scarlet hue to arterial blood, and has an absorption spectrum consisting of two dark bands of unequal width in the green (Fig. 5*b*).

Some years ago the German police had to determine whether an old man, whose charred body had been found in the ruins of his house, had died before or during the fire. A bare ten drops of blood were procured from the dead man's heart, yet these, when tested by the spectroscope, were enough to show that he was dead before the fire broke out, for the spectrum showed no trace of carbon monoxide. This gas, which occurs, *inter alia*, in the gas from motor exhausts, burning charcoal, etc., owes its notoriously poisonous qualities to the ease and firmness with which it combines with hæmoglobin, thus preventing it from doing its duty as an oxygen carrier. The compound thus formed is called carboxylhæmoglobin, and has a spectrum with two bands in the green which rather resembles that of oxyhæmoglobin, with the difference that the bands, instead of being of unequal width, are of about the same breadth.

Lack of oxygen may also occur in many illnesses, especially those connected with the heart and circulation,

which interfere with the supply of blood to the lungs. Excessive bleeding also gives rise to air-hunger. In such cases great relief may be obtained by breathing pure oxygen.

The actual consumption of oxygen by the body varies enormously. A man walking fast at five miles an hour disposes of 11 times as much oxygen as one lying in bed does in the same time, and produces a correspondingly greater amount of carbon dioxide. Carbon dioxide is much more than a mere waste product; it helps to regulate the rate of breathing. The faster a man walks, or the harder he works, the more carbon dioxide is produced, and the more acid his blood becomes, and this increasing acidity seems to stimulate the respiratory centre in the brain into making the lungs work harder, so the breathing becomes deeper and quicker. Owing to its influence, carbon dioxide is now used in medical practice to treat that distressing and often dangerous spasm of the breath, commonly called hiccough, which is a frequent sequel of certain operations.

Until quite recent times it was thought that carbon dioxide was dangerous when inhaled even in small amounts, but experiments have shown that men can breathe air containing five per cent for some hours without any ill effects save discomfort; but, as Sir Joseph Barcroft points out, the old rule that the carbon dioxide in rooms should not be allowed to rise above 0·1 per cent is still useful, since air that contains more than that amount of carbon dioxide probably contains other things as well. Recent investigations, too, have shown that in ventilation it is as important to keep the air moving as it is to keep it pure.

But the great importance of carbon dioxide in the scheme of things is the use that is made of it by plants. Most plants are like animals, and take in oxygen and give out carbon dioxide; but in full sunlight this is somewhat masked by the fact that green plants absorb carbon dioxide and give out oxygen, thus serving to keep the balance in the atmosphere, and more than that; for the whole physical life of the world is based upon the fact that green plants alone are able to manufacture food for themselves out of carbon dioxide and water. Despite much research by botanists, the exact nature of the process is still rather obscure, but there is no doubt that, with the aid of chlorophyll, the green pigment of leaves, energy is absorbed from sunlight through which various compounds of the nature of starch and sugar (which are composed of carbon, hydrogen, and oxygen) are built up from carbon dioxide and water, and oxygen given off. There is a pretty and well-known experiment which demonstrates this. A bunch of fresh green leaves is placed in a large bottle full of spring water, which is then inverted in a basin of water and left in the sunlight. After about an hour or two, bubbles of oxygen appear on the leaves and collect at the top of the bottle, and, if numerous, can be collected in a small test-tube, and the presence of oxygen shown by the kindling of a red-hot splinter.

There are few sights in nature more peaceful than that of green fields and woods on a summer's day, and yet every leaf and blade of grass is really as busy in its way as the crowded warehouses and factories of the city.

A minor but interesting use of carbon dioxide is its employment by the rock-boring mollusc, lithodomus,

which is a relative of the mussel. Like other sea-creatures of its kind lithodomus breathes by means of the oxygen dissolved in sea-water. When one of these molluscs fixes itself on to a rock, the carbon dioxide it breathes out acts upon the stone and softens it. Lithodomus is therefore able to remove the rock with its tongue and make a burrow for itself.

Now, when Lavoisier carried out his experiments on air, he named the gas which could neither support combustion nor life azote which is Greek for lifeless. This name had a certain vogue but is now supplanted by the one, suggested by Chaptal, of nitrogen, or producer of nitre saltpetre. The change was not an unsuitable one, for since Lavoisier's time it has been found that though nitrogen cannot support breathing, it has a great deal to do with the maintenance and growth both of plants and animals, being as essential in its way as oxygen. Animals derive their nitrogen either from the nitrogenous parts of other animals or their products (flesh, eggs and milk) or from the appropriate tissue of plants, notably cereals and members of the pea tribe. Plants, on the other hand, are able to obtain their nitrogen direct from the salts in the soil, and also from the free nitrogen in the air. This is possible through the work of many varieties of bacteria that live in the soil; in sterilised soil no nitrogen is taken up. Strangely enough, the activity of these bacteria is much increased if certain protozoa are present, despite the fact that protozoa feed on bacteria!

In some cases there is actual co-operation between bacteria and plants. It has long been known that plants of the pea family, instead of exhausting the soil

like most crops, enrich it to such an extent that they are often actually planted to restore the fertility of worn-out soils, and it has been found that these plants are in partnership, so to speak, with certain bacteria that grow in the curious nodules on the roots of peas, clover, etc., and provide their hosts with abundant nitrogen straight from the air.

Plants also obtain large quantities of nitrogen through the action of lightning. Nitrogen is not an active gas, and will not unite with oxygen under ordinary conditions, but the passage of an electric discharge is enough to cause the two gases to combine with the formation of oxides of nitrogen, and when the air is moist, as it is in nature, nitric and nitrous acids, which are brought down in the rain, combine with the minerals in the soil to make salts. Here again the bacteria come in, for they transform some of the compounds thus formed into others more suitable to the needs of the plants. There are also other bacteria which work in the opposite direction, and break up the salts, returning large quantities of free nitrogen to the air.

In farming, the soil is generally helped by nitrogenous fertilisers such as nitrates and salts of ammonia, which latter are a by-product, in great measure, of the gas industry. Formerly much saltpetre used to be imported from Chili, but now various processes are at work fixing nitrogen from the air. These were largely developed in response to the very grave warning given by Sir William Crookes at the 1898 meeting of the British Association. He pointed out that the population of the world was rapidly increasing, and therefore more and more wheat was required, and more and

more nitrogen needed to keep up the fertility of the soil. Farmyard manure and gasworks ammonia were insufficient to meet the demand, and even the great beds of nitrate in Chili would be exhausted in sixty years from the date of speaking. That would mean famine, for without fresh supplies of nitrogen the earth would begin to decrease in fertility; and yet while man was starving for bread and the wheat starving for nitrogen, it would be in the midst of all the nitrogen of the air, vast in quantity but useless, because it would be free and not in the form of salts. Needless to say, such a statement caused the greatest sensation, and research was undertaken, at first with disappointing results, but later on with success. This may be judged from the fact that during the Great War, owing to the then recently patented Haber process, Germany, despite the fact that supplies from Chili were closed to her, was able to manufacture nitrogen compounds for fertilisers and explosives.

In this country manufacture of synthetic nitrogen compounds is carried on successfully at the Imperial Chemical Industries factory at Billingham-on-Tees, where they are produced at prices which can compete satisfactorily with those of similar materials from other sources.

Oxygen, nitrogen, and carbon dioxide are the three constituents of the atmosphere which, along with water vapour, take the largest share in the maintenance of life. There are other gases which do not seem to have any direct bearing on human affairs and are usually called the inerts, for they are exceedingly unwilling to enter into chemical combination. It is for this reason that the principal member of the group, argon, is used

to fill 'gas-filled' lamps, since there is no risk of its shortening the life of the metal filament by combining with it. Another member of the group – neon – has recently come much before the public, since the red glow it emits under the influence of an electric discharge makes it very suitable for aerodrome and shop signs.

There is another constituent of the atmosphere, however, whose sudden disappearance would make life very uncomfortable, if not impossible. In the ordinary way the atoms of oxygen cling together in pairs, but by such means as an electric discharge or ultra-violet radiation some of the oxygen molecules can be broken up, and the odd atoms made to attach themselves to undamaged molecules, thus making a molecule consisting of three oxygen atoms, which possesses such distinct qualities, as a strong smell and very great chemical activity, that it has received the special name of ozone. The total amount of ozone in the atmosphere is very small – if it were all collected together at sea-level it would only make a layer $\frac{1}{8}$ inch thick – and yet this small amount of gas absorbs one-twentieth of the total energy of sunlight, which energy is used up in bringing about the oxygen-ozone transformation as described above. The rays absorbed are in the most active portion of the ultra-violet, and, if the ozone were suddenly to vanish, so potent would be the radiation let through that we should never be able to expose our skin to full daylight again. There also seems to be some connection between the weather and the amount of ozone in the atmosphere above a particular place, and a good deal of intensive research is going on all over the world into this and other aspects of the ozone question.

In addition to these permanent constituents of the atmosphere, there are what may be called additional ones. There is always a greater or less amount of solid matter usually described as dust. This comes from various sources. Large amounts of loose soil, sand, etc., are raised by the wind in every country, especially in deserts, which dust is not only carried hundreds of miles, but also lifted high into the air by the rising currents which are particularly common in connection with thunderclouds; indeed, the gloomy and sinister appearance of these latter is sometimes due to the amount of dust carried up into them by these currents.

Then, vast quantities of dust are thrown into the air during volcanic eruptions such as those of Krakatoa in 1883 and Katmai in 1912, quantities which are often great enough to produce gorgeous sunsets and weird effects, like blue suns and moons, and to cut off some of the sun's heat. Indeed, there is a theory that one of the causes of the great ice ages of the past has been excessive volcanic activity, that threw into the atmosphere such enormous amounts of dust as to cut off the solar heat, and so lower the temperature of the globe enough to cause an inordinate development of ice and snow.

Another source of atmospheric dust is the millions of meteors that are continually entering the earth's atmosphere from outside space, and being burned up by the heat caused by the friction of the air. With the larger meteors, or 'fireballs,' this dust remains visible for some time as a luminous train. In most cases this disappears fairly rapidly, but in others, like the Madrid meteor of 1896, it lasts for two hours or so; while the dust cloud left behind by the great Siberian meteor

of 1908 travelled all round the world, producing marvellous sunset glows. Cosmic dust, probably from meteors, is also believed to produce the luminous night clouds that can sometimes be seen in summer; they resemble cirrus, but are of a characteristic shining bluish-white colour, for, being 50 miles high, they are still lit up by the sun.

Another source of solid matter in the air is the sea, for the wind whips the spray from the crest of the waves and so becomes laden with salt particles, which in a gale may be transported miles inland. There are many instances of this on record, surely one of the most remarkable being that of the great storm of 1839, when a westerly gale carried sufficient salt across England to encrust trees and hedges near Alford, Lincolnshire, 140 miles from Liverpool. It is to this salt that many gardeners attribute the scorching of foliage that is often seen after a gale, and at least on one occasion it has caused trouble with electric power lines; the salt on the insulators turned to brine in the moist air, and caused a temporary but at the time mysterious breakdown of insulation and failure of current.

These salt particles, however, have a very definite use, for they form an important section of the different nuclei round which water-vapour has to condense to form raindrops or clouds.

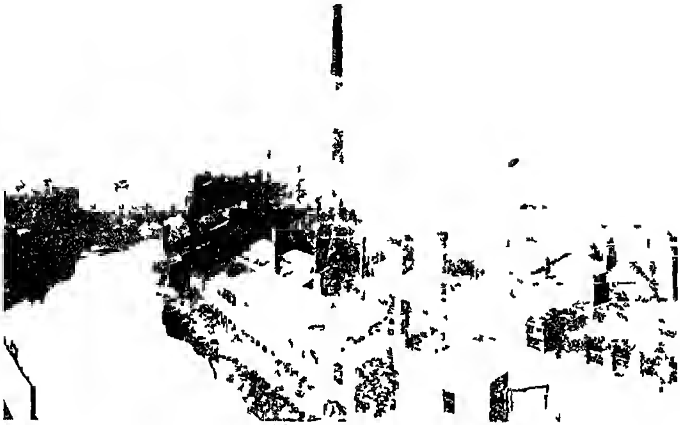
Another type of particle about which we in England know too much sometimes comes from smoke, which consists of soot, ashes, and drops of liquid tar. There has always been a certain amount of this smoke; it is produced in huge amounts in forest fires, but it has only become a problem in the last few centuries or so

with the growth of industry and the rise of large cities. The smoke of large industrial towns (Plate I) does untold damage to health, property, and vegetable life; it seems that the death-rate from acute lung diseases is increased by the coal-dust, smoke, and soot of industrial areas, and the lungs of the inhabitants, at death, instead of being pink, are more or less grey, and health must also suffer from the deprivation of sunlight. One of the things that struck the writer on a first visit to a famous northern city was how the summer sun seemed to shine through a veil. Buildings are coated with grime, while vegetation suffers, not only from lack of sunlight, but from the deposit of soot on the leaves that interferes with their natural functions. The vitality of any sort of plant usually decreases as the centre of an industrial town is approached, and some refuse to grow at all. The growth of aviation has also brought into prominence the effect of smoke on the clearness of the air, and it has been found that, with easterly winds, smoke from the industrial towns of France and Belgium can reduce visibility at aerodromes on our eastern coast.

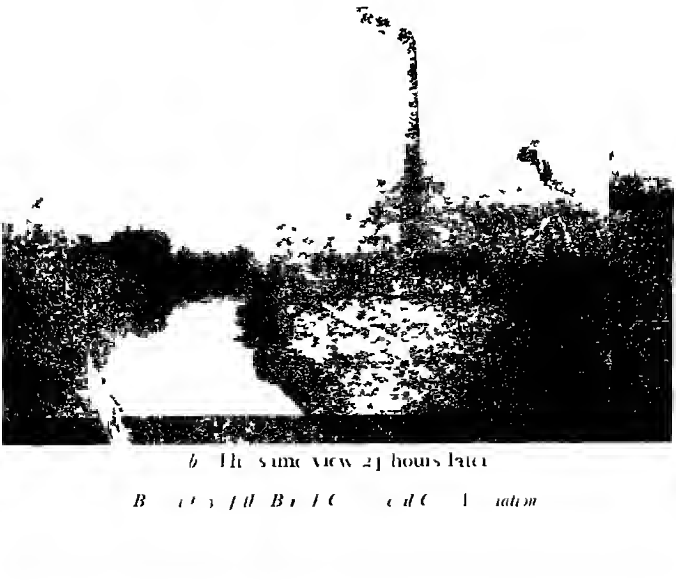
This pollution by smoke is naturally at its worst during periods of fog, which are generally times of no wind, and in the towns of Lancashire may reach such a pitch that those cotton mills that are not fitted with air-purifying plant have had to close down, since the polluted air was soiling the yarn as it was spun. In such cases, too, the fog often has an unpleasant tang, and brass becomes tarnished, for raw coal, when burned, produces not only soot, but that very objectionable gas sulphur dioxide, which comes from the burning of the sulphur in the coal. In contact with moisture, sulphur dioxide is changed into sulphurous

PLATE I

A Study in Contrasts



a View of Sh[illegible] on a working day



b The same view 2[illegible] hours later

B[illegible] [illegible]ation

PLATE II

A Sandstorm over the Pyramids (p 52)

'And there was thick darkness in all the land of Egypt'

By courtesy of Captain A G Buckham, F R P S

and sulphuric acids, which dissolve in rain and attack the stonework of buildings. They have also been known to cause tragedy. Some years ago a great sensation was caused by an alarming number of cases of illness and death in the highly industrialised portion of the Meuse valley near Liège during a fog, and the official inquiry showed that the fog, which was unusually persistent, was so heavily laden with acid sulphur fumes from the factories that after a few hours many persons found exposure to such an atmosphere fatal.

For the past six centuries the smoke nuisance has been the subject of legislation, for as early as 1306 Edward I forbade Londoners to burn coal, and two centuries later a proclamation of Elizabeth made its use illegal while Parliament was sitting, but it was only during the last century that the matter was taken up seriously, not only by the State, but by private enterprise. For the past fifty years the Smoke Abatement Society has done valuable work in educating public opinion, not only by emphasising the evils of smoke, but by popularising the use of smokeless fuels such as coke, gas, and electricity. Conditions in London – to quote one instance – have been much improved, and figures for 1936 show that the percentage of winter sunshine in the capital as compared with Kew had more than doubled since 1881. On the other hand, however, the amount of tar and sulphur gases had increased, the deposit of the former at one of the worst stations, Golden Lane, being 10·44 tons per square mile.

The air also contains many products of life. At the appropriate season it may be laden with pollen from trees or seeds, and, save perhaps in remote spots like

the Antarctic Continent, there are numberless bacteria and spores of fungi. During the descent of *Explorer II* from the stratosphere, a collecting-tube was kept open to the air between heights of about 13 miles to 7 miles, at which height it was closed. Later on, in the laboratory, some sterile nutriment was run into this tube, and the culture was then incubated. In two days' time there were 10 colonies visible, five of which proved to be those of bacteria, and five of mould fungi, all of which were of well-known types, and have a wide distribution.

Last, but not least, the air contains a variable amount of water vapour, but the importance of this is such that it will have to have at least two chapters to itself.

CHAPTER III

The Way of the Wind

Who can see the wind?
Neither you nor I.
But when the trees bow down their heads
The wind is passing by.

These words of Christina Rossetti surely sum up that characteristic of the wind which must have made it, to the mind of early man, such a marvel and a mystery. What was this thing, unseen and yet so real, whose comings and goings could not be followed, that to-day seemed to be non-existent, and yet to-morrow would be lashing the sea into fury, and bending – yes, uprooting – the mightiest trees? The pious Hebrew of the centuries before Christ spoke of Jehovah riding in majesty on the 'wings of the wind,' and pictured Him speaking to Job 'out of the whirlwind.' Later on, too, Rabbinical tradition also told of the angels of wind and of fire who died as soon as born. The ancient Greek poets sang of the winged sons of the north wind who sailed with Jason on the quest of the Golden Fleece, while the sculptors of Hellas depicted the winds as winged human figures, clothed, and bearing different symbols to represent their different characteristics. Thus, Zephyrus, the west wind, was depicted as a beautiful and lightly clad youth carrying fruits in his mantle, while Notus, the rainy south wind, was, appropriately enough, given a water-pot. The great

god of our own pagan ancestors, Odin or Wotan, was in some of his aspects a god of the wind.

All over the world, too, medicine-men and witches claimed to control the wind, and as late as 1822 old hags in Norway used to sell winds to sailors. The dislike of old-fashioned seamen to anyone whistling on board was probably a faint survival of the belief in sympathetic magic, i.e. the idea that the imitation of the whistling of the wind would result in the production of the thing itself.

Even in early days, however, there was some scientific knowledge, and the wise men of Greece produced a definition of wind which, save for some such qualification as 'along the ground' (a clause rendered necessary by what we know to-day about vertical motion in the atmosphere), is hard to improve upon. They defined wind as 'motion of the air.'

Air moves because of differences in the pressure of the atmosphere that are set up by contrasts in temperature. When air is heated, it expands and becomes lighter, so the pressure falls. When air is cooled the reverse happens; the air becomes denser and the pressure rises. The flow of air is from regions where the pressure is high to regions where the pressure is low, and the greater the contrast in pressure or barometric gradient between two regions, the quicker will the air flow as wind, in the same way that water will run quicker down a steep slope than down a gentle one. The speed of the wind is largely governed by the steepness of the gradient; the winds in tropical cyclones, where the pressure usually falls 2½ millibars in one mile, are generally much more violent than those in the depressions of these latitudes, in which, even in

intense ones, the pressure only falls the same amount in 25 miles. For the same reason the calms and light winds experienced in fine weather systems or anticyclones are due to the very small gradients that occur therein.

The general relation between wind and pressure was summed up very ably about 80 years ago by Professor Buys Ballot in the rule that bears his name, and which has been of the greatest possible assistance to sailors and others who wish to know their position in regard to the centre of a storm. Buys Ballot's law states:

Stand with your back to the wind and pressure is lower on your left hand than on your right in the northern hemisphere. South of the equator the reverse is true.

Now, if the earth were at rest, and had a uniform surface – either all land or all water – the problem of the wind systems of the world would be a fairly simple one. There is a belt round the earth at the equator, where the rays of the sun strike down steeply throughout the year, and give, in consequence, a greater and more constant supply of heat than they do to other parts of the globe. At the two poles conditions are very different. Owing to the curvature of the surface of the earth, the rays of the sun strike at a glancing angle, so that even in summer the polar regions receive little direct heat, and in midwinter each pole in turn receives none at all. Accordingly, great contrasts in temperature are set up between the equator and the poles which are enough to start a circulation of air between them. Light, heated air rises above the equator and spreads outwards towards

the poles to replace the cold, dense polar air, which sinks and flows towards the equator, where it would arrive, on a stationary earth, as a north wind. Actually something of the kind does happen, but there are complications.

In the first place, the earth is not at rest, but is revolving on her axis, carrying the air with her, once in 24 hours, with the result that the air above the equator is travelling at 1,000 miles an hour, that above the poles at (theoretically) nothing, and that in between at an intermediate speed which naturally varies according to latitude. The effect of this on the winds blowing from the poles to the equator and vice versa is to give them a twist, to the right in the northern hemisphere, and to the left in the southern. This effect can be seen in the Trade winds; on a still earth they would blow north and south instead of north-east and south-east, as they actually do.

Then, too, in addition to this main circulation, there seem to be additional ones in the regions between the equator and the poles, the whole apparently working together, to use the simile suggested by Dr. A. H. R. P. Goldie, like a train of geared wheels, working one in the other. There is much distortion, too, of the general circulation of air, chiefly in the northern hemisphere; but the fact is that the earth's surface is not uniform, but broken up into land and water. Land both gains and loses heat much more rapidly than water does, so that both in summer and in winter there are great contrasts of temperature between the continents and the neighbouring oceans, contrasts which are often great enough to set up wind systems of their own, which range in importance from the land and sea

breezes of our own coasts to the great monsoons of Asia.

In spite, however, of all these complications, the wind systems of the globe are fairly well marked (Fig. 6, p. 43), especially in the southern hemisphere, which contains the bulk of the ocean and is thus fairly free from the disturbing influence of land.

Beginning at the equator, there is a belt of low pressure, the oceanic portion of which has been long known to sailors as the doldrums – regions of light, variable winds or dead calm broken by violent storms. In the days of sail, a ship might pass through the doldrums in a day, driven by one of these storms; more often she would linger there for weeks, either 'ghosting through' by the aid of her lofty royals and skysails, which could use the faintest breath of wind, or perhaps becalmed for days, 'a painted ship upon a painted ocean,' while the pitch oozed from her seams, and food and water ran short. In the early days of the Australian emigrant traffic, before steam was introduced, they earned the name of the 'Wayside Grave,' for many a passenger on those overcrowded vessels gave up the struggle to live ere the ship won through those close, steamy latitudes to the Trade-wind belts beyond.

North and south of the doldrums blow the Trades – north-east in the northern hemisphere, and south-east in the southern. Their name does not come, as might be supposed, from their one-time usefulness to commerce, but from the nautical expression 'to blow trade,' which means 'to blow regularly,' which, subject to certain variations in direction and strength, is the great characteristic of these winds. So far as the N.E. Trade is concerned, the first to discover this regularity was

Columbus in 1492; indeed, it was a source of great anxiety to his men, and probably to himself, how they would be able to return home against the wind, for the three ships that went on that famous voyage were clumsily built, and therefore difficult to handle when it came to beating to windward.

The Trades are not very deep; the N.E. Trade in the Atlantic often reaches a height of only 3,000 feet, though it has been known to blow at the summit of the Peak of Teneriffe, which is 12,160 feet high. Above the Trades are the winds known as Anti-Trades, for at one time they were supposed to be return currents taking back polewards the air that had been brought equatorwards by the Trades. Recent research, however, has shown that the real explanation of these winds is more complicated, and will probably have to wait till our knowledge of the circulation of the upper air is better than it is at present.

It is the action of the Trades on the waters of the sea that is largely responsible for the creation and maintenance of the great ocean currents.

Beyond the Trades lie the regions of high pressure, light winds, and fine weather in which they take their origin. These belts of calm are known to sailors as the Horse Latitudes, a name which has been handed down from the days of sail, when there was a large trade in horses between this country and Jamaica. It often happened that the ships were so delayed in these regions by lack of wind that water ran short, and overboard the unfortunate horses had to go. The passing of the sailing-ship may have robbed the sea of some of its glamour, but it has also done away with much hardship and tragedy.

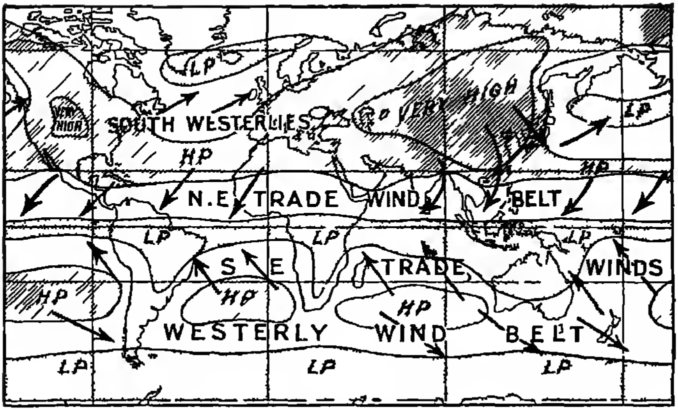
North and south of the Horse Latitudes come the zones of the westerly winds, regions bounded on the Poleward sides by the easterly winds of the polar regions, winds better developed at the South Pole than at the North. This boundary between the polar winds and the westerlies is called the Polar Front, and is the main breeding-place of the travelling weather disturbances or depressions that rule the weather of these latitudes. The Polar Front is by no means fixed; from time to time great bursts of polar air break through the westerlies and the Horse Latitudes and reach the Trade-wind belts, which is another instance of how very complicated the general circulation of the atmosphere really is.

The British Isles lie in the region of the westerlies, and that is why our winter climate is so mild, since to reach these shores the winds have to cross the warm waters of the Atlantic Ocean. Sometimes, however, this westerly circulation of the air breaks down, and everyone knows how, in winter and spring, this country is often invaded by cold easterly winds from the winter high pressure over Europe, and how, in the summer, the Horse Latitudes, as they follow the sun north, may extend their influence to our coasts and bring us the dry summer of the Mediterranean lands.

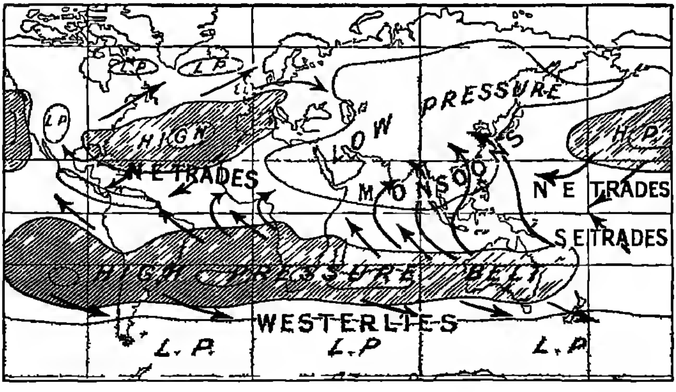
In the southern hemisphere, however, where the ocean extends round the globe practically unimpeded by land, the westerlies blow with a strength and steadiness that has earned them the name of the 'brave west winds,' under the influence of which many an old-time clipper has done her 2,000 miles a week on the Australian voyage. It is in the westerlies, too, that the wind shows its wave-making powers to the fullest;

in the free waters off Cape Horn the waves roll in an endless procession of 'greybeards,' 30 to 50 feet high – in the eloquent words of Maury, 'tossing their white caps aloft in the air, looking like the green hills of a rolling prairie capped with snow, and chasing each other in sport.' And, even in the comparatively restricted space of the Atlantic, the westerlies can produce monsters of size and power, as witness those giant combers that, in the gale of 1824, tossed five-ton blocks of stone over Plymouth Breakwater like so many playthings.

So much for the general circulation of the atmosphere. There are also several smaller circulations caused by local conditions. The most important of these arises from the presence of the great land mass of Asia, which becomes very hot in summer and very cold in winter. In winter the cold land creates a large area of high pressure, which sets up an outflow of winds which blow out to join the N.E. Trade and bring dry weather to India and South China. This state of affairs persists throughout the winter and spring, but by May the land has warmed up to such an extent that the high pressure has been replaced by a low-pressure system which draws in the winds from the Indian Ocean and China Sea. The usual S.E. Trade in the Indian Ocean is drawn right across the equator, obliterating the belt of calms, and, being deflected by the rotation of the earth, arrives in India as a rain-bearing south-west wind. This is the South-west Monsoon, which is so vital to the millions of India, for, should it fail, poverty will be the lot of multitudes of peasants during the coming year. Monsoons also occur in Northern Australia and East Africa, and it is



(a) January



(b) July

Fig 6. Winds and Pressures

(From *The World*, by Dudley Stamp; Longmans)

to the African Monsoon that Egypt owes its existence as a nation, for the water that feeds the Nile comes ultimately from the monsoon rainfall on the Abyssinian mountains.

The ordinary sea and land breezes of our coasts might be described as miniature Monsoons, for they arise from the differences in temperature between land and sea. In the day the land becomes warmer than the sea, the air in contact with the soil is heated and rises, and is replaced by a cool current from the sea. At night the reverse takes place, though the breeze is usually weaker. In this country the sea breeze only extends about a mile inland, but in the warmer parts of the earth, where the circulation is stronger owing to greater temperature contrast between land and sea, these breezes are much more vigorous, as is the case in Palestine, where the cool current from the Mediterranean reaches Jerusalem, 40 miles inland. Further north, as the researches of Dr. Ashbel have shown, it undergoes a curious change; on reaching the edge of the deep trench in which lies the Sea of Galilee, it falls from the hills and arrives at the lake as a warm, gusty wind which is rather dangerous to small boats, especially at a certain point between Tiberias and Kinereth, which the fishermen call the 'Fortress of Devils.'

This warming of a wind by descent down a slope is due to the compression of the air as it descends, and occurs in many parts of the world, especially in Switzerland, where it gives rise to the Föhn, and on the eastern side of the Canadian Rockies, where the resulting warm dry wind is known as the Chinook. A Chinook has been known to raise the temperature 40° F. in 15

minutes. This wind is of great importance to the farmers of Alberta, since through its influence the high grazing-grounds are freed from snow much earlier in the year than otherwise would be the case.

There is another kind of warm wind, the best known form of which is the southerly wind that blows in front of a depression in the Mediterranean, and is called variously, according to the country, the Leveche, Ghibli, Khamsin, or Scirocco. This wind not only comes from the hot Sahara Desert, but is warmed by its descent from the North African plateau to the coast, and so becomes hot and dry, and frequently dust-laden. Its most unpleasant form is perhaps that of the Scirocco of Sicily and Italy, because to reach those countries it has to cross the sea, from which it picks up moisture, so that it becomes damp, and is therefore much more trying than when it was dry.

On the north coast of the Mediterranean occur examples of another kind of wind, known as Katabatic, which is caused by the flowing of cold and heavy air off high ground. These Katabatic winds attain their greatest development off the coasts of the great ice-covered tablelands of Greenland and the Antarctic Continent, but the most famous and best known examples are the Mistral of Provence and the Bora of the Adriatic. During winter, when pressure is high over Central Europe and temperature is low, a flood of cold air pours down towards the Adriatic and, in favourable circumstances, such as the presence of a low-pressure system over the sea, may attain gale force. Similar conditions over the Balkans give rise to the wind known to the Maltese as the Gregale, which

sometimes blows so violently that ships in the Grand Harbour at Valletta keep steam up so that they can leave at once for the open sea. The Mistral is the same sort of wind, that blows down the Rhône valley when there is high pressure over Central France, and low over the Gulf of Lyons. The popular opinion of its character is best expressed in the local proverb that classes it with the floods of the River Durance and the Parliament as one of the three scourges of Provence, and the impression of cold created by it is shown by the saying that the Mistral 'takes off your clothes.' Somewhat similar to the Mistral is the Helm Wind of Cumberland, which is a torrent of cold air that, in favourable circumstances, pours down from the moors of Crossfell into the valley beneath, and is said to be so violent at times that the turnips are uprooted in the fields!

Now, although winds had been familiar to man for countless generations, it was long before any attempt was made to classify them according to their strength, beyond such rough estimates of force as are expressed in words like 'gale,' 'breeze,' etc., and this vagueness of language is a great handicap to students when endeavouring to find out, say, the exact strength of the storms that are said to have played havoc with the Spanish Armada. In the contemporary accounts that have come down to us, the Spaniards use expressions like 'tormenta' and 'temporal,' and make vague remarks such as, 'The sea so high that all the mariners said that they had never seen the like in July'; while the English narrators, such as Sir John Hawkins, write phrases such as 'a little flaw took them.'

It was only in 1806 that Admiral Sir Francis Beaufort prepared the first really scientific scale of wind

force, which he based upon the amount of sail which a man-of-war could carry with safety. In recent years this Beaufort Scale, as it has been called, has not only been brought up to date, and so revised that it can be used by observers inland as well as at sea, but it has been related to the actual speed of the wind as measured by anemometers. Of these instruments there are two main types in use. The first, invented about 1846 by the Rev. T. R. Robinson, consists of four (or, in some modern patterns, three) hemispherical cups at the end of crossed arms of metal, so pivoted at the centre that the difference in pressure set up by the wind between the inside and the outside of the cups makes these spin round. This instrument usually is set to give the total run of the wind in miles since it was started, but there is also a device, on the same lines as a speedometer, which shows the speed at any moment. Recently a modification of this type of anemometer, in which the cups are replaced by six fins on the edge of a copper disc, has been brought into use in America, notably at the observatory on Mount Washington, which at present holds the 'blue ribbon' for the world's highest measured wind speed, namely an hourly run of 173 miles on April 12th, 1934, with gusts reaching 225 miles per hour.

These record gusts, however, were measured with a stop-watch, and for many reasons it is much more satisfactory if the wild winds can be induced to write their autographs, so that they can be inspected at leisure, and preserved for future reference. For instance, the inquiry into the Tay Bridge disaster of December 28th, 1879, would have been much facilitated if exact records and times could have been available

of the gusts during the gale in which 1,000 yards of the bridge were blown into the river at the moment when the Edinburgh to Dundee train was crossing. As it was, though evidence was available as to the hourly run of the wind at the time of the accident, the Secretary of the Meteorological Council had to admit that the figures he gave for the gusts were only estimates. But, about 13 years after this disaster, W. H. Dines published the first account of the anemometer which is now known by his name, and which is used in the stations of the Meteorological Office. The instrument is worked by the difference in pressure between the pressure created by the wind blowing on an open tube and the suction produced by its passage past holes in an upright tube. This pressure and suction are transmitted by suitable tubes to a specially shaped float in a tank in the observatory building. The pressure tube is connected to the inside of the float, and the suction tube is connected to the space above the float, the net result being that the float rises and falls with the varying speed of the wind. Through two pens, one connected with the float and the other attached to the vane that keeps the mouth of the pressure tube facing the wind, records both of direction and speed can be obtained on a chart that is divided into hours, so not only the force but the time of a notable gust can be fixed. Thus it is known that the record gust for the British Isles which was registered by the instrument at St. Mary's, Scilly, during the great storm of December 6th, 1929, not only came from south-west and reached 111 miles per hour, but took place at 7.20 p.m.

This form of anemometer does not work very well

with light winds, probably owing to the laek of pressure. The pressure of the wind arises from the impaet of the air on the windward side, and from the suetion that simultaneously oecurs on the leeward side of any objeet, and for light winds is eomparatively small; for instanee, when the wind is strong enough to blow out a flag, which is taken as equivalent to 10 miles an hour, the pressure is about a quarter of a pound on every square foot. It is when the wind speed reaehes 35 miles per hour, and the pressure is 3·6 lbs. on a square foot, that ineonvenience is felt in walking against it. At gale foree and over, mueh higher pressures are experieneed; gusts of 100 miles an hour, sueh as are eomparatively frequently experienced at Falmouth and other plaees on the west eoast, would give a momentary pressure of 30 lbs. on the square foot. Facts like these have to be taken into consideration by engineers when designing bridges and sueh-like structures, and the pressure on the side of large liners during severe gales may be enough to render it advisable to eancel movements from docks or quaysides until the weather moderates.

The foree of the wind diminishes with height owing to the decreased pressure of the air, and at the height of Mount Washington, 6,284 feet, it is redueed one-fifth, so that, even during the reeord gale mentioned above, the observers deelared they had little trouble in going about their neeessary outdoor duties at the observatory, espeeially sinee they were more sheltered from the wind than the anemometer at the top of the building.

But anemometer records not only reeord the speed of the wind; they give very interesting and valuable

information about its nature, showing that it is not a steady stream of air, but is broken up into gusts and eddies, so that the trace of the pen is not a single line, but a ribbon whose breadth varies according to the exposure of the instrument, being narrower at places where the wind blows across flat country, and broader where the wind blows over trees, hills, or roof-tops, which set up eddies in the stream of air in much the same way as rocks cause whirlpools to form in the current of a river. The formation of eddies by any obstacle is illustrated below, and in the case of houses

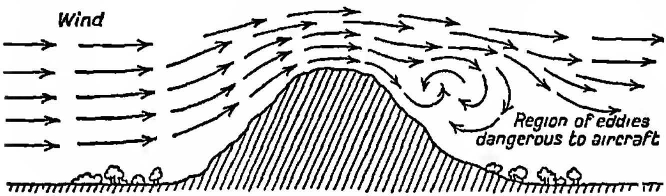


Fig. 7. Eddies near a mountain

is often rendered visible by the drift of smoke. The disturbances set up by hills are such as to be a real danger to aircraft, and have caused many accidents, which is not to be wondered at when measurements show that eddies in the lee of a hill may cause up and down currents with a rate of 1,500 feet a minute. On the other hand, these currents can be used by glider pilots, who have made some wonderful flights under their influence.

Anemometers, however, can only measure winds at the surface of the earth, or at the few mountain-tops which possess observatories. Winds seem to extend to all levels in the atmosphere, but, owing to lack of information, our knowledge of the upper regions is

comparatively incomplete. For winds within the first five miles – that is, to just below the stratosphere – much information can be gained by watching the movements of clouds, and it has been found that the speed of the wind increases with height, and that its direction tends to become more westerly, as may be often noted by comparing the drift of the clouds with that of smoke.

Another method of investigating the upper winds is by watching the flight of small balloons.

When the height of the clouds is known, the actual speed of the upper winds can be found, and observations show that at the cirrus level, which is a little below the base of the stratosphere, winds of 200 miles an hour are quite common. Information from higher levels is rather meagre, but sometimes it is possible to watch the drift of the luminous trails left behind by the large meteors called fireballs, and these have shown that winds with speeds up to 150 m.p.h. occur at heights of 50–60 miles. The dust thrown into the atmosphere by the great eruption of Krakatoa in 1883 also showed the existence of an east to west wind over the equator with a speed of 80 miles an hour at a height of 17 miles.

The wind plays many parts in the order of nature. It is, of course, part of the great general circulation of the atmosphere, a circulation necessary to the proper functioning of the world as the home of life. It has other lesser but interesting and important functions, as one of the forces that are continually moulding the face of the earth. It acts in two ways – by erosion and by transport of material.

Sometimes holiday-makers are careless enough to

leave empty bottles behind on the beach. If one of these bottles is examined, it often appears to have been frosted. This is due to the blowing against the glass of the particles of sand, which act like the sand-blast used in industry for etching glass or rubbing down the rough parts of machinery. In many dry regions this continual blowing of sand by the prevailing wind has resulted in the wearing away of rocks, and, as these rocks are often composed of materials of different hardness, the result has been to make them assume the most fantastic shapes, like those that have been nicknamed 'The Dancing Bear,' 'The Monkey's Face,' and 'The Idol Rock' in the well-known group at Brimham Rocks, on the Yorkshire moors.

But the principal work of the wind as a geological agent consists in transporting material. Any wind above Beaufort 4 (15 miles per hour) will raise dust. In the desert, every wind raises sand, and sandstorms have been the terror of travellers in such parts from time immemorial. The winds that blow out of the Sahara are loaded with such great quantities of sand that the sky is obscured and turned yellow, the air being rendered so thick that buildings can only just be distinguished at a distance of about 600 yards; indeed, many biblical scholars have thought that the 'darkness which could be felt,' which was the ninth plague of Egypt, really was a Khamsin! (Plate II, p. 33). The same thing happens in other desert regions; in Australia, for instance, it is said that during one of these storms men have stood by their horses and seen nothing except a vague outline through the whirling dust.

But the sand is not only carried by the wind to lands bordering the desert; it is often borne hundreds of

miles. In May 1937, during a south-westerly gale, yellow sand fell in Canton Basle in such amounts that the countryside seemed wrapped in a thick mist. Examination of this showed that it was of African origin and must have passed over the Alps at a height of 12,000 feet. At the same time there was a fall of red sand in the Engadine.

Sand-dunes are also caused by the action of wind, which heaps up the sand in ridges. They are particularly common in deserts, especially those of Asia and Africa, and also occur on coasts where there is a prevailing on-shore wind, as is the case on the shores of Brittany and parts of Cornwall. These dunes are continually on the move, and the only way to stop their march is to bind the sand by planting grass and trees, otherwise they travel on and on, burying in their progress fields, vineyards, farms, churches, and even whole villages.

Important as the work done by the wind is in the world of lifeless matter, it is not more so than that done by it in the realm of life. Many flowers, especially those of trees and grasses, depend upon the wind for pollination; indeed, it is thought that this was the primitive method, and that pollination by insects came later in evolution. Wind-pollinated flowers are usually inconspicuous, and produce large quantities of dry and powdery pollen, which is often seen rising above pine-woods, for instance, like a cloud of smoke. In April 1937 pollen carried by the wind from Fontainebleau fell in a veritable rain at Versailles. These wind-pollinated flowers show special adaptations. The male flowers are often grouped in long catkins which sway in the wind, and have long stamens hanging out of the

flower, while the female flowers are provided with large, rough stigmas, freely exposed to the air. In many cases, too, the flowers come out before the leaves, so as to avoid any accidental interference with the free passage of the pollen. Many plants, too, such as the sycamore and thistle, have seeds adapted for dispersal by the wind; the one has an aeroplane wing and the other a parachute of down.

In the animal world, too, the wind plays an important part. The air is the means by which scent is conveyed to the nerves of smell in the upper part of the nose, and those with any knowledge of wild life will know how impossible it is to approach deer or any other game downwind.

And the wind has even had an influence upon man. For centuries he had to depend upon it to grind his corn and to drive his ships, and even in this mechanical age there are hundreds who still derive pleasure and health from the handling of wind-driven yachts. Sometimes the wind has played havoc with man's nerves. One of the traditions of old Quebec concerns Le Braillard (the Wailer) de la Madeleine. For many years weird shrieks that in stormy weather proceeded from a wood on the Madeleine River, in the Gaspe Peninsula, used to terrify the settlers in that locality, until one night there arrived a missionary, the Rev. Painchaud. That evening the wails from the wood were worse than ever, and M. Painchaud, noting the terror of his companions, and probably guessing the cause of the noise, attached an axe to the sash of his cassock, and boldly entered the haunted wood despite the prayers and entreaties of his friends. It was not long before he came upon Le Braillard. Two trees had

grown together in the shape of a large X, so that their trunks pressed together in such a position that when the wind blew strongly they rubbed against one another. Having found the ghost, the padre proceeded to lay it by chopping down one of the trees. Since that time Le Braillard has never howled again.

In addition to the friction of the two trunks, some of the wails of Le Braillard were probably due to eddies set up by the narrow opening. Much of the howling of the wind is due to eddy motion at the angle of roofs, etc. It appears that eddy after eddy is set up at the edge of a roof so frequently and so regularly that a more or less musical note is produced, the pitch of which rises with the speed of the wind.

More pleasant to hear is the humming of telephone wires that arises from the eddies caused by the wires in the air as it passes by them. The actual note produced varies according to the speed of the wind and the size of the wire, and when this note is such as to be in tune with a natural note or harmonic of the wire, the wire itself vibrates in sympathy, and the loudness of the note produced is much increased. The once fashionable Æolian harp is worked on the same principle, and the rather strange quality of the music produced is due to the fact that some of the harmonics are not those used in ordinary music.

Even the trees are given tongues by the wind, tongues that vary from the roar of the forest that in many parts of the world is rightly held to be a presage of storm, to that pleasant sound so aptly described by Spenser as being 'like the sowne of swarming bees.' Every species of tree has its own voice; the low Æolian murmurs made by the wind blowing against the large branches

and twigs of the oak are very different from the sibilant notes that proceed from the fine and numerous needles of the pine.

And the wind has its own voice. A friend of the writer's has described how the approach of the 'Southerly Burster' of Southern Australia, the coming of which is usually preceded by a short lull, is announced by a roar. Similarly, it is recorded how one night some Alpinists, who were watching a distant storm, were startled by a strange rushing noise unlike anything they had ever heard before. A few moments later, the peak on which they were encamped was struck by a squall. In an ordinary gale the approach of individual gusts may sometimes be heard, the displacement of masses of air probably being enough to cause that most characteristic sound of 'a rushing mighty wind.'

CHAPTER IV

Cloudland

We are the Clouds, of splendid hue
Rising from sea with garments ever new.
We are the breath of Ocean old –
Who rest awhile, then journey far
Marching with swift, resistless tread
O'er plain and mountain.

ARISTOPHANES, *The Clouds*, 274

Of the many thousands of millions of tons of water vapour which are always present in the atmosphere, a vast amount is invisible, but an equally vast amount can be seen, and from the earliest times has attracted the interest and attention of the human race. References to the clouds occur in the mythologies of all races, from our own pagan ancestors, who thought of them as threads spun by the goddess Frigga, to the Polynesians, who, so similar are the workings of the human mind, regarded them as due to the like domestic activities of 'Ina, who was for ever preparing native barkcloth, and stretching it out to dry and bleach on the blue sky.

At an early date, too, the connection of the clouds with present and coming weather was realised, as is shown not only by the writings of the ancient Hindu sages such as Kalidasa, who flourished about 2,000 years ago, and who, in his poem, 'The Cloud Messenger,' gave a good description of the path of the welcome rain-bearing monsoon cloud over India,

but in the countless weather proverbs relating to clouds that have come down from the past. How soon the beauty of clouds was appreciated by man it is not easy to say; passages in the Psalms, and the conception of the 'thunderbird' found in both Central African and North American lore, seem to indicate that the majesty of the stormcloud early impressed itself upon human imagination. Shakespeare was obviously interested in cloud forms. In *Hamlet* we read: 'Do you see yonder cloud that's almost in shape of a camel? . . . It is backed like a weasel. Or like a whale? . . .' (Plate III).

But perhaps the real appreciation of the beauty of clouds came with the Romantic movement of last century, which produced Shelley's masterpiece, the accurate cloudscapes of Constable, and Ruskin's eloquent tribute to the glories of cloudland in *Modern Painters*. And in these days the aeroplane and the camera have revealed to man that, great as are the beauties of the earth and sea, they are rivalled by the beauties of the sky; indeed, many would think the beauties of earth are enhanced by those of the heavens. Mountain scenery would lose half its peculiar charm were there no ever-changing wreaths and caps of cloud to reveal and veil in turn. It is to the clouds that the sunset owes much of its pageantry, for, beautiful as is the unclouded setting or rising of the sun, surely there would be something lacking if there were no majestic piles of cumulo-nimbus for his rays to fire into the likeness of the new Jerusalem, or no delicate threads of cirrus to glow pink against the sky, 'like' – to quote a great writer – 'the drifted wings of many companies of angels' (Ruskin).

PLATE III

Dost thou see a cloud that's like a whale?

By courtesy of John Murray from Vol. I of Scott's Last Expedition

PLATE IV

Tufted Cirrus (p 60)

By courtesy of C P J Cave Esq , M A J P

And, in addition to all these beauties, part of the charm of clouds lies in their infinite variety, which renders it almost impossible to imprison the various forms within any rigid system of classification. Yet, as with human beings with all their diversity of character, it is possible to distinguish certain main types of personality, so clouds can be placed in different groups. Even as long ago as the Vedic age of India, the Rishi Angiras mentioned twelve kinds of clouds and their nine forms, and the Greek philosopher Theophrastus (373 B.C.) distinguishes 'streaks of clouds' from clouds like 'fleeces of wool,' but no really systematic work was done till the last century, when the French biologist Lamarck devised a scheme of cloud classification. About the same time (1803), in England, Luke Howard published his own scheme, which was so satisfactory that, with a few modifications, it is now in use all over the world. Howard distinguished three principal forms, to which he gave Latin names, viz:

Cirrus, a lock of hair;
Cumulus, a heap;
Stratus, a layer;

and also used combinations of these. Many other workers, such as the Rev. Clement Ley and H. Hilderbrandsson, have elaborated Howard's original scheme, and more recently the matter has been taken up by an International Committee, whose definitions will be followed here, and under which clouds are grouped as high, middle, low, and 'with vertical development.' To this class belong Howard's cumulus, which are often so thick that they extend from low to high levels.

Highest of all the ordinary clouds come the delicate

threads of CIRRUS, which in this country are generally to be found at a height of five miles, though sometimes they descend as low as two, and in the polar regions may be found almost on the surface. Though at present there is not much exact knowledge as to how they are formed, their tenuous structure is due to the small quantities of water vapour available in the cold regions in which they form, for the colder the air the less water it can hold. Generally they seem to be composed of ice crystals, though sometimes they may be made up of super-cooled water-drops – that is, drops at a temperature below freezing-point. Cirrus takes very varied forms, such as tufts, plumes, curved lines ending in tufts (Plate IV, p. 59), and straight bands which run right across the sky and, owing to perspective, seem to converge on the skyline, forming thereby a boat-shaped figure that is well known to sailors under such picturesque names as 'Noah's ark,' 'Mary's ship,' or a 'salmon.'

Cirrus is a fine-weather cloud, but it is formed in large quantities round the summit of thunderclouds, and also in the front part of a bad-weather system, and often the first sign of a change is the appearance of cirrus travelling rapidly from the west. If a storm is on the way, this cirrus is generally succeeded by the form called CIRRO-STRATUS, which covers the sky with a whitish veil which does not blur the outlines of the sun and moon and, as it is composed of ice-crystals, often gives rise to haloes.

There is a very delicate form of this cloud called CIRRO-NEBULA, which is so fine that often its presence is only shown by brilliant halo effects.

In a bad-weather system, cirro-stratus is followed by

ALTO-STRATUS, which is like thick grey cirro-stratus, and is often formed of snowflakes. Sometimes it is so thick that the sun and moon are hidden, but often they show through vaguely, as if shining through ground glass. This is the 'watery' sun of weather lore, for this appearance is frequently followed by rain as the alto-stratus thickens into

NIMBO-STRATUS, the raincloud. Like alto-stratus, it is formed by the slow ascent of large amounts of air which has been made to rise either by mountains or the flowing together of air currents. As the air rises, it expands and cools till at last it cannot hold all the moisture it originally contained when warmer, which moisture condenses out as cloud and rain.

Above the alto-stratus level, at about 20,000 feet, occurs one of the most beautiful of clouds and one of the rarest,

CIRRO-CUMULUS, or mackerel sky, which consists of small, very pure white flakes or globes, arranged in groups, lines, or waves. It is formed by the churning of a layer of air by eddies; the upper part of the layer is cooled, and, if there is enough moisture, cloud is formed. The tops of the cloudlets lose heat more than do the bottoms, and so become unstable. Somewhat similar to cirro-cumulus, but coarser and lower in the atmosphere, is

ALTO-CUMULUS, in which the cloudlets are larger and show shadows. It has one particularly interesting, not to say useful, form, called turret cloud, or, more scientifically, alto-cumulus castellatus, the presence of which is almost a sure precursor of thunder. This cloud resembles ordinary alto-cumulus, but each cloudlet bulges upward like a small cumulus,

an effect caused by damp unstable air above a stable lower layer, a condition that also favours thunderstorms.

The two lowest types of clouds are perhaps the most dull.

STRATO-CUMULUS is the lumpy grey cloud that often covers the sky for days at a time in winter, producing the condition most aptly termed 'anti-cyclonic gloom,' though, when this cloud is less continuous, it may enhance the beauty of the landscape, for sunbeams may stream through the chinks in that fanlike effect known as 'the sun drawing up water.' It is a fact that a view of a certain south-coast town, which by chance or design incorporates this effect, has proved one of the most popular ever produced by the particular firm.

STRATUS is the lowest of all clouds, and is often described as being like a fog but not resting on the ground. It frequently occurs in patches, which are apt to form over and among hills and mountains, which is a reason why high ground, especially near the sea, is liable to fog all the year round, a fact which must be borne in mind by anyone wishing to tramp or climb in such districts. Indeed, it is well on such excursions to have a map and compass, so that, if one is suddenly fogbound by the formation or drifting over of low cloud, a course can be steered to some point of security such as a road or farm. The advice of local inhabitants is also worth taking.

The last group of clouds, those with 'vertical development,' is also one of the most interesting and important.

CUMULUS, the typical 'woolpack' cloud of a fine summer's day, results from the process called convection. It is a common sight on a hot day to see the

air above the ground quivering by reason of the countless little threads of hot air that are streaming upwards off the heated ground. Needless to say, such convection currents of hot air are very strong in tropical countries, where they are a great nuisance to airmen. A friend of the writer once had the joystick of the machine he was flying over the Egyptian desert collapse in the air, owing to the violence of a sudden upward current. The 'dust-devils' of desert countries, and their poor relations, the miniature whirlwinds that develop on roads in this country, are due to these convection currents, which are rendered visible by the dust they carry with them. These whirlwinds, probably owing to the suddenness with which they often arise, have a prominent place in folklore all over the world, being put down to the activities of the fairies or similar beings. Even in this country they may be quite impressive; a whirlwind has been known to lift a heavy cricket sight-screen, and in desert countries there is no doubt about their imposing nature; in some cases they have reached the height of 2,000 feet or more.

But outside desert regions the rising air is not only warm, but moist; also, except after spells of fine warm weather, the upper air is much colder than that below, so that when the warm, moist surface air begins to rise, it not only loses heat by the act of ascending, but passes into colder regions. The result is that sooner or later some of the moisture is bound to come out in the form of vapour, and, the conditions being right, the cumulus clouds are formed. The flat base, so characteristic of these clouds, marks the level at which the water vapour begins to condense; the rounded tops show where the head of the rising column of vapour is

protruding into a cold space. In fine weather these clouds often die away at sunset, for they are constantly being replenished by a stream of moist air rising from the earth beneath, and, when the sun goes, convection stops and the supply of moisture fails. These clouds can be formed anywhere where there is sufficient contrast between the temperature of the surface and upper air to start upward currents of air; they often fringe coastlines, being over the warm land in the afternoon and the warmer sea at night. Plate V (p. 68) shows such a fringe of clouds lying along the coast of France. They frequently have been seen over large fires, such as the one that destroyed Tokyo in 1923. Sometimes, indeed, the cumuli over fires become so large as to give a shower, which may be the reason for a rather curious request made to the High Sheriff of Staffordshire, on the occasion of the visit of Charles I in 1636, that 'being desirous that the country and himself may enjoy fair weather . . . His Majesty hath commanded me to write unto you, to cause all burning of Ferne to bee forborne, untill his Majesty be passed the country.'

Cumulus clouds vary very much; the soft woolly clouds of the summer afternoon are on an average about 1,200 feet thick, but, given an adequate supply of moisture and strong enough convection currents, they may grow large enough to give a few 'heat drops,' or gradually develop into the towering

CUMULO-NIMBUS, or true thundercloud, a great mountain of vapour whose summits may reach the height of 20,000 feet and be visible 160 miles away. The ascending currents of air in these clouds are extremely violent, for which reason they are shunned by airmen, who know well that, should they be caught,

they would be in for a gruelling time. Balloonists have had the most harrowing experiences in such clouds; one had his craft 'spun round with frightful velocity,' while his clothes were covered with ice. These air currents seize hold of the water vapour, which is at once carried to the top of the cloud, where it freezes and streams out in a whitish veil of snow greatly resembling cirrus, the presence of which is a sure sign of very heavy showers, and possibly thunder. In very well-developed clouds this cirrus spreads out, causing the cloud top, when seen from the side, to resemble an anvil. The quantity of vapour in some of these huge storm clouds is almost incredibly vast. Even in this country clouds containing from 10 to 30 cubic miles of vapour are quite common, and some have been seen containing up to 100 cubic miles.

If cirro-cumulus is the most beautiful cloud, cumulo-nimbus is the most impressive, especially at sunset, or at night when lit up by lightning.

Cumulus may also be formed by the forced ascent of warm moist air, undercut by a cold current. To this is due the striking roll of cloud that sometimes accompanies a line-squall. This is caused by a current of cold air meeting a current of warm moist air, which is forced to rise all along the line, thus producing an immense wreath of cloud which may be dozens of miles long (Plate VII).

Such are the chief types of cloud, which in nature are continually passing into one another. Thus daytime cumulus may become strato-cumulus at nightfall, and cirrus or cirro-stratus change into cirro-cumulus. In addition there are certain special forms of clouds worthy of mention.

Cumulus and stratus are often torn by the wind into fragments, in which case the name of the cloud is given the Latin prefix *fracto* (broken). The scud of sailors is fracto-nimbus.

Very often the lower surface of clouds, especially in thundery weather, develops a series of bulges, due to downward bursts of cold air, which type of cloud is known popularly as 'pocky cloud,' but officially as mammato-cumulus.

Particularly characteristic are the forms of clouds associated with mountains. All over Europe are to be found proverbs corresponding to the Worcestershire saying:

> When Bredon Hill puts on his hat,
> Ye men of the vale beware of that;

or the more poetical Roxburgh one:

> When Ruberslaw puts on his cowl,
> The Dunion on his hood,
> Then a' the wives of Teviotside
> Ken there will be a flood.

Many of the European proverbs are repetitions of those quoted above, but the saying about Monte Venda, the highest of the Euganean hills, is more original:

'When Monte Venda is making bread, if it is not raining now, it will to-morrow.'

The cause of these 'caps' on hills is that high ground deflects the air upwards. In fine weather the cold caused by this forced ascent is not enough to bring about condensation, because there is not enough damp in the air, but on the approach of a bad-weather system the moisture is increased, so cloud is formed by currents up the windward side of the hill.

Another picturesque form of mountain cloud is the banner, which is caused by a strong breeze blowing against a mountain peak. This sets up a current up the lee side of the peak, which feeds the cloud that streams out from the mountainside, constantly evaporating at one end, and as constantly being renewed at the other by the condensation of fresh water vapour. A particularly interesting variety of this type of cloud is the 'plume' of Mount Everest, which consists, not of droplets of water, but of ice crystals.

Of similar formation are those clouds known scientifically as lenticular, which, during the Great War, were sometimes mistaken for enemy airships. The current of air in which they form makes them take a streamlined shape.

Another very interesting mountain cloud is the fog cascade, which is found, in the appropriate conditions, all over the world, but is best known in its Cape Town form. When the moist south-easter blows against Table Mountain, the flat summit becomes covered with the famous 'table-cloth,' which spreads over the entire plateau, while 'its north border hangs over the precipice drapery fashion; but during very strong winds it pours down like a cataract to about 1,000 feet from the top' (Sir Thomas Maclear, sometime Astronomer Royal at the Cape).

It is not uncommon to see, hanging from cumulonimbi, small pendants of cloud. These mark the beginning of the characteristic and dreaded funnel of the tornado or waterspout, which are, in essence, eddies of air. These eddies are so violent that the surrounding air is cooled, and any moisture present is

condensed, and, as it were, clothes the eddy with a whirling column of vapour of weird and terrifying aspect that has left marks in the folklore of many peoples. African natives living round Victoria Nyanza have a legend about a great snake that lives in the water, and, from time to time, emerges with a fearful roar to devour men and boats. Again, the Swahili, on the east coast of Africa, regard the waterspout as a sign that God is angry with a whale (to them a kind of sea-serpent), and has let down a rope to draw the struggling monster up to heaven !

The coming of the aeroplane has brought changes into cloudland. Sometimes in the track of a plane are to be seen whitish streaks of cloud that often look very like the smoke used for skywriting. They have also been seen to originate at the nose of the machine and come streaming back over the wings. Various suggestions have been made as to the cause of these clouds. It has been thought that the sudden reduction of pressure due to the motion of the craft, especially in front of the propeller, leads to cooling and condensation if there is enough moisture present, or condensation is promoted by the exhaust gases, which not only contain water vapour but millions of the nuclei around which the water droplets condense.

There is another theory which seeks to explain these clouds by the effect of the passage of the machine through a layer of super-cooled vapour. This peculiar state in which water vapour exists unfrozen at temperatures below freezing-point is not at all uncommon in the atmosphere, and is the source of one of the greatest dangers to which aircraft are exposed, for this condition is very unstable, and contact with anything solid

promotes freezing. An aeroplane, therefore, passing through such a layer of air, will rapidly gather a rough-smooth coat of ice, and if the super-cooled vapour is, as is frequently the case, condensed in the form of a cloud, the pilot, in addition to the anxieties of blind flying, has to encounter the great disturbance of the stability of the machine caused by the ever-increasing load of ice, which increases the drag, bends the wings, and creates alarming vibrations in the structure of the craft, besides adding to its weight, sometimes to the extent of half a ton. It is not surprising, therefore, that during the last few years most intensive research has been undertaken, not only into the causes of icing of aeroplanes, but in the production of protective devices which can be fitted to the machine.

As regards blind flying, recourse can be made to instruments. Under the hood of the Miles Magister in Plate VI, is a pilot undergoing training in instrument flying.

Aeroplanes not only cause the formation of clouds; they may disperse them. More than one case has been reported of a patch of cloud being cut clean in half by the passage through it of an aeroplane; in one case the lane of clear sky closed up again, and in another it remained till the cloud dispersed. An instance has also been recorded of an aeroplane cutting a lane for itself through a shallow fog.

Another aspect of clouds which has an important bearing upon flying is that of height or ceiling. At the great Coronation Naval Review of 1937, the grand fly past of the Fleet Air Arm had to be curtailed, for the onset of low cloud made the return flight and dipping in salute over the royal yacht impracticable. So

important is this question of low cloud that estimates of height are now included in regular weather reports, so that pilots may have the latest available information.

The height of clouds is determined in various ways. At observatories, where the pilot balloons used in connection with measurements of the wind are available, it is easy to find the height of clouds. The rate at which the balloon rises is known, so that all that is necessary is to release the balloon and note the time that elapses till it vanishes into the cloud. At night a searchlight is sometimes used. A powerful beam of light is thrown straight upwards till it strikes on the cloud, producing a definite patch of light. Meanwhile, at the other end of a measured base line, an observer measures the altitude of the patch of light by means of the simple instrument for measuring angles called the alidade, which, as its name shows, goes back to the days of the brilliant Arab civilisation 1,000 years ago. From the information thus obtained it is easy to work out the height of the bottom of the cloud. The searchlight can also discover the presence of layers of clouds that are otherwise invisible owing to their thinness. Daytime measurements of an exact nature are often carried out on much the same lines, being made at the same time on the same cloud by two observers at the two ends of a long base line. The height of the cloud is found by calculation from the observations, but the apparatus required is elaborate and the observers have to be connected with each other by telegraph. Observers, therefore, at places like health resorts, which have no special equipment, and amateurs, such as Scouts and Guides, who watch the clouds out of interest, have to fall back on other

methods, such as estimating the height of clouds against any local hill or mountain, or the summit of a lofty building such as Durham Cathedral.

The direction from which clouds are travelling is also of interest, owing to the information furnished as to the upper winds, and may be best observed by sighting the clouds against some fixed point such as a flagstaff or the roof of a building. It is also advisable to stand as near as possible directly below the chosen point, and to observe only those clouds which are right overhead, otherwise errors due to perspective are apt to creep in. At observatories, instruments known as nephoscopes are used; in one type the cloud is reflected in a black mirror, and in another type a cross-piece is rotated till the cloud appears to travel along it, the direction being read off on a graduated dial. The cross-piece is furnished with spikes, and the time taken for the cloud to travel from spike to spike can be measured, which measurement, provided the height of the cloud is known, can be used to calculate the speed at which it is travelling. For the same reason the mirror nephoscope is provided with graduated circles.

When observing clouds in this way it is advisable to wear smoked glasses, to prevent eyestrain. The black mirror is also useful, and can be made quite easily by coating one side of an ordinary piece of glass with black varnish. It is especially useful for viewing the delicate higher clouds, cirrus and cirro-cumulus, the intimate structure of which shows up well against the dark background.

Other observations, habitually taken in connection with clouds, concern the amount, which is estimated on a scale of tenths, ranging from 0 when the sky is

absolutely clear to 10 when it is completely overcast, with no patches whatever of blue sky showing through the clouds. These islands are in one of the cloudy regions of the world, the average degree of cloudiness for the whole year being six-tenths to seven-tenths, with, of course, variations either way, the cloudiness being, as a rule, less in the summer and more in the winter. This large amount of cloud is due to the British Isles being situated in the north temperate belt of westerly winds and low pressure. The region just to the north, between Scotland and Iceland, is more cloudy, having a general average of seven-tenths and over. Similar conditions prevail in the corresponding zone of low pressure and westerlies in the Southern Ocean, and in the belt of rains and calms round the equator. Here there are some especially pronounced patches of cloudiness off the coasts of Chili and French Equatorial Africa respectively, and, during the monsoon season, large areas of cloud develop over south-eastern Asia, where, in India and Burma, the average may reach eight-tenths or more. Similarly, in the corresponding season in the southern East Indies and north of Australia – which, being the southern hemisphere, is after Christmas – a large patch of heavy cloudiness develops for the time being, though not to such a degree as those which appear over Asia.

Astronomers are inclined to think that these areas of cloudiness would form one of the most striking features of the earth as viewed from some point in space – say from the moon or from one of the nearer planets. The clouds of the equatorial low pressure and rains would appear as a dazzling white girdle, which would shift slightly north and south with the seasons, and which

would be bordered on both edges with darker zones corresponding with the less cloudy trade wind and 'horse latitude' regions. These darker patches would reach their greatest intensity over the deserts; one would stretch from the north of Africa over Arabia into the heart of Asia, and smaller patches would be visible over South Africa, Australia, and the south-western United States, not only over the land but extending into the oceans owing to the dry air being carried seawards. Indeed, the only places where the white of clouds would be at all prominent would be those eastern shores open to moist on-shore winds; also the monsoon would bring a patch of cloudiness to the region of the China Seas in the appropriate season.

The waxing and waning of the monsoon would probably be clearly visible to an observer in space owing to the formation and disappearance of clouds.

North and south of the dark trade-wind zones and 'horse latitudes' the imaginary watchers in space would see brighter regions corresponding to the belts of westerlies and their clouds, for it is estimated that outside the deserts there are seldom to be found areas of more than 1,000 square miles entirely free from clouds. The endless procession of bad-weather systems or 'depressions' that haunt the latitude of these islands, and the corresponding ones in the southern hemisphere, would be clearly visible as white patches, separated by darker regions. On the whole it would seem that as an object of astronomical study the earth would be less easy than Mars, with his thin cloudless atmosphere, and much more interesting and much less disappointing than Venus, whose real surface is for ever invisible beneath a thick veil of cloud.

The dazzling white surface attributed to the clouds as seen from space is not a mere effort of the imagination. The exact shade that clouds assume depends upon their position and thickness. Some thin clouds like cirrus let so much light through that they never appear grey; others, like alto-cumulus, are sometimes white and sometimes show shadows, according to their degree of thickness. The lower clouds from alto-stratus downwards cut off greater or less amounts of direct light, and so appear various shades of grey, though, as there are always stray rays of light about, reflected from other clouds or scattered by the air, it is very seldom, if ever, that a cloud looks dead black, and there is always a certain amount of light even on the dullest and most overcast day. On the other hand, the passage overhead of a fully developed cumulo-nimbus, a mass of vapour whose contents in cubic miles run into double or even treble figures, and whose thickness in feet is measured by the 10,000, often brings about a sudden and rather alarming darkness, which darkness is also a characteristic of heavy snowclouds. Even a small cumulus cloud may be thick enough to appear black when it comes between one and the sun, in which case, however, it often develops a silver lining. This expression seems to have been coined by Milton, for in his early and charming work, the *Masque of Comus*, occur the lines:

> Was I deceived, or did a sable cloud
> Put forth its silver lining on the night?

But when the clouds are so placed as to reflect the sunlight, things are very different. A swarm of small water-drops, such as make up the clouds, reflects about

four-fifths of the sunlight falling upon it, and thus it happens that the clouds that are so dull when in shadow become dazzling white when situated in the correct position. One of the most striking experiences in an airman's life is to make an ascent through the clouds on a dull winter's day, for, once the cloud layer is reached and traversed, the gloomy grey canopy is exchanged for a gleaming billowy plain of a whiteness rivalling, if not surpassing, the untrodden snows of the Alps. Across this plain skims the shadow of the aeroplane or balloon, a shadow often encircled by the rainbow rings of a 'glory.'

Now the water-drops in a fog or in certain kinds of cloud, especially cirro-cumulus and alto-cumulus, are often about the same size as the waves of visible light ($\frac{1}{30000}$ to $\frac{1}{57000}$ inch), and, when this is the case, instead of the light-waves being reflected or scattered, they are diffracted – that is, they break their rule of always travelling in straight lines and run round the droplets, meeting behind, just as waves of the sea run round and meet behind a suitable rock. And the result of this setting up and meeting of two wave systems is interference. In the sea there are places where the water stands extra high where two crests meet, or extra low where two troughs meet, or level where a crest and trough meet; and with white light colour effects are produced, so that the sun or moon, shining through a suitable cloud, is surrounded by rings of colour. These coronæ are sometimes confused with haloes, but can easily be distinguished from the latter because they are not separated from the sun or moon by a definite space, but encircle the luminary closely, and also have the red outside, whereas with the halo the red is inside.

Another difference is that often the series of colours in a corona are repeated twice, or even thrice. They are best seen round the moon, but are most gorgeous when produced by the sun, in which case they are well seen through smoked glasses, or reflected in the black mirror or water to reduce the glare.

The size of coronæ varies with that of the drops; the larger the drops the smaller the corona. The iridescent clouds that are sometimes seen owe their beautiful play of colour to fragments of very large coronæ formed in the minute water-droplets of which they are composed. After a great volcanic eruption the sun is sometimes seen surrounded by a large corona, called 'Bishop's Ring,' caused by the diffraction of light by very small dust particles in the upper air.

Coronæ are caused by the sun shining through clouds of the appropriate kind. Glories are formed in a slightly different way. It used to be supposed that they were caused by the diffraction of light reflected from the deeper parts of a fog or cloud by particles near the surface, but the Indian mathematician, B. B. Ray, has shown that the more probable explanation is that the drops act like a swarm of little mirrors. Light can be diffracted not only by running up against small obstacles, but by passing through small holes, and Ray's theory shows that light reflected from each droplet would behave as if it had come through a tiny hole, and give diffraction colours, hence the glory.

Glories are not only seen from the air; they often occur round the shadow of an observer thrown on a bank of fog, a thing which is very common in mountainous districts. The most famous example is the 'spectre of the Brocken' in Germany, the uncanny

effect of which is enhanced by the fact that a shadow thrown in such circumstances may be mistaken for a real person seen dimly through the mist, and this idea of someone at a distance creates the further illusion that he is gigantic.

To a glory Mount Omei in China owes its sanctity in the minds of numbers of devout Buddhists, who resort to it by the 10,000 to see the Fo Kuang, or 'Glory of Buddha.' The sight is certainly remarkable. With the sun in the appropriate position, the watcher sees his shadow in the centre of a rainbow-like glory that seems to float on the sea of white clouds below, and it is not uncommon for some of the more fervent of the pilgrims to be so wrought upon by the spectacle that they throw themselves over the precipice, in the belief that they will be received in the arms of Buddha and carried to Paradise. Indeed, it is to their resemblance to the nimbus with which the forms of beatified saints are surrounded in religious art that glories owe their name.

Clouds play a great part in the regulation of temperature. The temperature of any place is affected by many things, such as height, distance from the sea, time of year, etc. But, everything else being equal, temperature is largely the result of the balance between incoming and outgoing radiation. On a clear day, at a season when the sun is high in the heavens, his light and heat pass through the lower layers of the atmosphere with scarcely any loss on the way, and, on reaching the ground, are partly reflected and partly absorbed. The portion of radiation absorbed heats the ground, and is radiated out again in the form of long heat-waves. In the daytime more heat is received by the earth than is

lost by radiation, and so the day is warm. But as soon as night falls heat is rapidly radiated out into space, and the temperature falls. This effect is especially marked in the desert, where the air is dry. During the 'cold weather' in the Punjab the thermometer may reach 80° F. in the day and fall to 32° or less at night. Even more extreme seems to be the case of the planet Mars, the atmosphere of which appears to be very dry, for the assumed daily range of temperature at the Martian equator reaches the fantastic amount of 180° F.!

Should the air be loaded with water-vapour, however, matters are very different, for, though the water in the atmosphere permits the passage of the comparatively short-wave radiation from the sun, it strongly absorbs the longer waves given out by the earth. Thus, in the humid tropics, even clear nights are often oppressive.

In cloudy weather conditions are different. A sheet of cloud not only prevents the heat of the sun from reaching the earth, but it also stops the heat from the earth being lost into space. Thus on cloudy days there is often little difference in temperature between day and night. In summer, cloudy days are cool because the clouds keep out the heat. In winter (when the income of heat from the sun is less than that expended by radiation), cloudy days are warm, because the earth's heat is prevented from escaping.

But, strangely enough, though radiation from the earth is favoured by the absence of cloud, it often gives rise to cloud. During clear, cold nights the temperature of the air in contact with the ground may fall so low that it may reach the dewpoint, or level at which condensation takes place, with the result that any

moisture present separates out as visible cloud or fog. An inversion – that is, a state of affairs in which the temperature, instead of falling with height, as it usually does, changes in the opposite way – is set up in the lower layers of the atmosphere (for instance, during a London fog the thermometer on the top of the Victoria Tower, Westminster, stood $7\frac{1}{2}°$ F. higher than one in a screen $4\frac{1}{2}$ feet above the ground), and condensation produced by the mixing of air through eddy motion or turbulence. Inversions also develop in valleys, for the cold, heavy air trickles down the slopes into the bottoms, which become filled with a white sea of fog out of which the hilltops rise like islands.

These radiation fogs often reach their greatest thickness about two hours before sunrise, and in summer are generally gone by noonday. But in winter they may last for days, and frequently cover a wide area, causing great dislocation of transport services by land, sea, and air. These fogs are especially objectionable in cities, owing to the presence of smoke. An interesting result of modern developments in London is that in recent years the centre of the city has been free from fog on the ground. It is supposed that this change is due to the warmth from the large amount of central heating in the many new buildings, as well as to the cleaner streets and the increase in the area covered with waterproof surfaces such as tarmac.

Fogs may also be formed by the passage of a current of warm, moist air over a surface colder than itself. Fogs at sea are mainly of this type; for instance, the notorious fogs off the Great Banks of Newfoundland are due to warm, damp air from the Gulf of Mexico blowing over the cold water of the Labrador current.

Sea-fogs are not very deep, and are frequently so shallow that the masts of a ship may protrude above them, but at the level of the deck they are dense enough. Many captains, especially those in command of large and well-found vessels, would rather have a storm than a fog any day, for strong construction and powerful engines may be very helpful in a gale but useless in a fog, during which the only thing to do is to crawl along sounding the siren and hoping for the best. Many people spare a kind thought for the sailor in stormy weather, they might well do so during fog. Readers of Kipling will not forget his poem on fog in the Channel, 'The Wet Litany,' with its refrain of 'Libera nos, Domine !'

And it seems now that deliverance has come, not only for the sailor but for the airman. The recently invented Aldridge Detector is a form of radio set that is sensitive to the long waves radiated by all objects at ordinary temperatures. These waves have great powers of penetration, and, under conditions in which the eye can see nothing, any object, such as a hill, ship, or iceberg, can affect an instrument five miles away. A needle is made to move across a dial following the movement of the object, and red and green warning lights show whether it is to port or starboard.

In cold weather fog may be at such a low temperature that it consists of super-cooled droplets. These are apt to solidify when they come into contact with anything solid, such as foliage or wire netting, forming a deposit known as rime.

The distinction between fog and mist is one of thickness, mist being a fog which is thin enough to allow objects 1,100 yards off to be seen. When the mist is

due to solid matter such as dust or smoke it is called 'haze.' Scotch mist is really low cloud, which, in upland districts, often comes down nearly to ground level, producing a very unpleasant combination of drizzle and mist.

Nearly all clouds and fogs, from the lowest fog to the highest cirrus, occur in the bottom five miles of the atmosphere. The stratosphere (see Chap. XII) is nearly free from cloud, but not quite, for very occasionally clouds are observed the height of which is shown by photographs and measurements to be nearly 15 miles. These clouds, which have been carefully studied by Professor Carl Störmer of Oslo, show very beautiful colours, which seem to arise from the diffraction of light by very small water-drops, which, at that height, must be super-cooled.

Clouds have been noticed and talked about for generations, but never have they been so much studied as at the present day. They have been closely inspected from aeroplanes and balloons, their changing shapes have been fixed by photography, and their growth and decay recorded by the cinema. The ways and means of their formation are being investigated in the laboratory of the experimenter and the study of the mathematician. Yet, despite all this activity, the day is far distant, if ever it comes, when man will come to the end of all the secrets hidden in cloudland.

CHAPTER V

The Drops that Water the Earth

> Hast thou entered the treasuries of the snow,
> Or hast thou seen the treasuries of the hail? . . . .
>
> Hath the rain a father?
> Or who hath begotten the drops of dew?
>
> Job xxxviii. 22, 28

As is the case with so much that goes on in the atmosphere, the causes that lead to the falling of the rain from heaven are as yet only partly understood; indeed, the more the matter is studied the more complicated it seems to become. However, enough is known for the outlines of the process of rain-making to be given.

The atmosphere always contains a greater or less amount of water vapour, which is continually being replenished by the evaporation constantly going on during the day from every open water surface, from the widest ocean as well as from the smallest puddle; and not from water alone. A great deal of moisture is also evaporated, not only from the leaves of plants, but from the skins of human beings as perspiration, which is one of nature's ways of keeping the body at an even temperature. That is why the damp heat of the tropics, where the large amounts of moisture in the air hinder evaporation from the skin, is much more disagreeable, and even harmful, than the dry heat of the deserts. The cooling brought about by evaporation is

due to the taking of energy to turn the liquid water into vapour; sometimes this energy may come straight from the sun, but sometimes it may be taken from the water or surrounding air, a fact which has many useful practical applications. In India, for example, water-soaked curtains or 'tatties' are hung over doorways – the evaporation of the water cools the air – and in the same country drinking-water is also cooled by placing it in a porous pot, out of the sun, but exposed to the wind. Some of the water soaks through the sides of the pot and is evaporated, cooling the pot and the rest of the water. A good way to keep meat and butter cool in hot weather is to stand them in a plate in a little water, and cover them with a piece of muslin which dips in the water all the way round the plate. This arrangement, which serves well save in very hot weather, is especially handy in camp and in houses without refrigerators, and works on the same lines as the standard hygrometer, used to measure the humidity of the air. This instrument consists of two thermometers, one of which has its bulb wrapped in muslin which is kept moist. The evaporation from the wet muslin cools the instrument, which reads lower than the companion instrument, the difference between the two being greatest when the air is dry, and least when it is moist. The actual degree of humidity is calculated by means of tables.

There is another form of hygrometer which is used for taking continuous records, and is worked by the effect of the changing amount of moisture in the atmosphere on the length of a bundle of human hairs, the stretching of which moves a pen which travels over a chart.

Moist air is lighter than dry, and, therefore, tends to

ascend, a process which takes place more easily in some states of the atmosphere than in others. The temperature of the air under average conditions usually falls at the rate of 3° F. for every 1,000 feet, but often this rate is exceeded, and, when this is so, damp air rises easily and rain is likely. Such a state of affairs is often brought about by the passage of a cold current of air over warm seas; the surface air rises, and the moisture contained therein begins to condense out, not only through the lower temperature, but through the cooling due to expansion, first as cloud and later on as rain, for the difference between the two is really one of degree, since both cloud and rain consist of drops of water. The droplets in the cloud, however, are very small indeed, averaging about $\frac{1}{125}$ of an inch in diameter, and are so light that, though if left to themselves they would fall slowly, the gentlest upward current of air is enough to buoy them up; so clouds float. But, as condensation goes on, the drops increase in size, and finally are able to fall through the upward currents of air.

An important cause of rain is the forced ascent of air over hills, as, for instance, happens when the moist, warm south-westerly winds from the Atlantic blow against the mountains of Wales or Cumberland. The rainfall in these districts is the greatest in the country; indeed, the total of 247 inches during 1909 at Llyn Llydaw, Snowdon, has never been exceeded during the period in which records have been taken in these islands; and in warmer countries, where the air can hold a greater quantity of moisture, the combination of mountains and warm, moist winds produces the heaviest rainfalls in the world. The N.E. trade wind

blowing against the mountains of Hawaii gives Kauai 476 inches in a year, and in the mountains of Assam the monsoon, for the same reason, brings Cherrapunji an average of 450 inches – figures which mean that if all the rainfall at these places could be collected, it would form a lake nearly 40 feet deep.

One important result of this heavy deposit of moisture in upland districts is that places in the lee of a range of hills lose a good deal of rain. The Midlands and east of England are much drier than Wales or Cumberland, and in the tropics the results are much more startling; for instance, the western slopes of the Western Ghats of India that are open to the monsoon have a rainfall of 250 inches a year; the eastern slopes have only 25 inches.

Another way in which air may be made to ascend is by the meeting of two currents of different temperatures. When this takes place, the warmer current rises over the colder just as if the latter were a hill, and it is in this way that much of the rain in this country is produced, being derived as it is from the bad-weather systems known as depressions or cyclones, and which can be regarded, in the main, as due to the clashing of warm and cold currents of air. There is still much to be learned about the actual mechanism of these depressions, but it seems that the warm air rises over the cold, thus giving rise to dense clouds and rain. In the front part of the depression this rising up of warm, moist air is gradual, and produces that sort of steady rain which has caused some of the heaviest rainfalls recorded in this country, such as the record fall of 9·56 inches in a day at Bruton in Somerset. It is this type of rain that gives rise to severe floods, and, as it seems that

most of it falls at night, it is no doubt the kind of rain that has given rise to the east country saying, 'Night rains bring drowned fens.'

At the rear of the depression, however, the lifting up of the warm air takes place with a jerk, which causes the rain to fall in a heavy shower. This type of rain is akin to that caused by the third way in which air can be made to rise – by the heating of the surface layers of the atmosphere. The process is the same as that which causes the growth of cumulus clouds: the ground becomes heated by the sun and communicates its heat to the air, which expands and rises. If the air contains enough moisture and the temperature up above is low enough, not only may a large cumulo-nimbus cloud be formed, but the condensation set up may be vigorous enough to give a shower of comparatively short duration but of the greatest possible heaviness. The second heaviest recorded rainfall in this country – that of 9·40 inches on August 18th, 1924, at Cannington, in Somerset – was due to this kind of rain, as was the world's record rainfall of 1·03 inches in one minute in the San Gabriel Range, California, on April 5th, 1926. Such a downpour constitutes a true cloudburst.

Most of the cloudbursts reported in the Press are really very heavy showers; but occasions actually do arise when the rain seems to fall, not in drops, but as a solid mass of water. It is believed that the rising air currents that occur in connection with large cumulo-nimbus clouds may be so strong that the rain is actually buoyed up by them for a time; then when, for some reason or other, the strength of the air currents diminishes, the accumulated mass of water falls as if

poured out of a bucket. These cloudbursts are common in mountainous districts; the slopes of our own north country fells are marked in many places with the 'scaurs' made by the water pouring down the hillside after some such downpour as the one which in 1893 ploughed up 30 or 40 acres of the peat on the Cheviots to a depth of five feet and piled it in enormous heaps. This kind of rain, whether from cloudbursts or ordinary thundershowers, often does a great deal of damage by washing away the soil, especially where the reckless cutting down of trees, or careless or ignorant farming, has taken away from the soil its natural covering. Indeed, the question of soil erosion is now receiving the most serious attention both in tropical and south Africa and in the United States, where the reclamation of soil, impoverished by bad farming, is one of the activities of the board in charge of the great Tennessee Valley scheme.

These heavy rains, too, are much less effective in the long run than steadier kinds. Thus in England an annual rainfall of 30 inches is quite adequate for agriculture, because it is distributed throughout the year. At Pretoria, however, it is quite inadequate for that purpose, not only because the climate is warmer and the loss by evaporation greater than is the case in the British Isles, but because the 30 inches fall mostly as heavy showers, which compact the surface soil into a hard layer over which the water runs but does not soak in. Therefore that part of South Africa is pastoral.

Rainfall is the most important feature of climate after temperature, but its effects are much more complicated, as they depend not only upon the actual amount of rain, but upon its nature and its distribution

throughout the year. For instance, wheat may be grown in Western Australia with less than 10 inches of rain a year, because the rain comes just at the right season; and the dry summer of the Mediterranean lands assures the ripening and safe ingathering of the harvest. But further north, in Britain, the farmer has always the threat of a wet summer hanging over him, and so close is the connection between the dryness or otherwise of the summer and the nature of the harvest, that the records of the price of corn in the days before the Napoleonic wars, when Britain was still mainly an agricultural country, can be used as an indication of the weather of the summers. Thus, in the last half of the eighteenth century, which was rather wet, prices paid for corn in Scotland were about 11*s.* more than those paid during the previous five decades, which were very dry. 'Drought,' says one proverb, 'never brought dearth in England,' and 'When the lavants rise, corn will be dear,' says another. Lavants is the Sussex name for the intermittent springs which appear and flow for a short time in chalk country, after prolonged and heavy rain, the most famous being the Croydon Bourne, or 'Woe Water,' whose appearance is supposed to presage some disaster. Various explanations for this reputation are possible; perhaps it is due to the association of the stream with very wet weather, the occurrence of which brings trouble to an agricultural community, or perhaps because of the fevers that used to be bred in the marshy ground that is left behind after the stream has disappeared; or perhaps, merely, the idea grew because the flowing of the bourne is not very common, which, to certain minds, would mean that it must be a portent of something.

The real reason for the flowing of the Croydon Bourne and similar streams is, that in certain districts the top of the underground water or water-table is nearly at the surface, and as all springs (saving those of a mineral character like that at Bath) derive their water from the rain, excessive and lengthy rainfall raises the water-table to such an extent that it rises through the porous chalk and appears on the surface, appearing first in the lowest portion of the valley and creeping upwards till it forms a stream several miles in length.

It was anxiety as to the water-supply of this country that really gave rise to the organised study of rainfall in Britain. Such great droughts occurred in 1857, 1858, and 1859 that Mr. James Glaisher doubted that the deficiency would ever be made up, and these remarks led to the founding of the British Rainfall Organisation by Mr. G. J. Symons, a body of voluntary observers, now numbering over 5,000, to whose work 'we,' in the words of Sir Richard Gregory, 'owe all our knowledge of British rainfall.'

Rainfall is measured by means of a rain gauge, a copper cylinder of standard size which is fixed in the ground at a standard height. The gauge is inspected once a day, usually at 9 a.m., and the water, if any, is measured in a special glass measure graduated to read in inches or in millimetres (25 to an inch). The rain gauge is a very ancient instrument. It is said to have been used in ancient India, and the Science Museum at South Kensington possesses a Korean gauge dating from the fifteenth century; but those in use in Europe originated in Italy, the inventor being a Benedictine monk, Dom Bernardo Castelli, the friend of Galileo. It is said that during the great drought of 1639,

Castelli was struck by the way a lake, by shrinking and filling up again, became an indicator of the rainfall, and reasoned it would be possible to use a vessel in the same way.

The rainfall varies very much from year to year even in the same place, these variations being probably bound up with the continual changes in the general circulation of the atmosphere. Thus, the disturbances of that circulation, whatever they were, that caused the S.E. trade wind to be unusually weak during 1923, seem to have led to a wet summer in 1924, while the great spring drought of 1893, when some places in the southern counties had no rain for 50 days, was caused by a northward extension of the usual high pressure system over the Azores. And no doubt, since the whole atmospheric circulation is kept going by the heat of the sun, the changes in solar radiation that are continually going on must have a great deal to do with variations in rainfall.

Though it is true that lighting a grass fire may sometimes cause a cumulus cloud to form and give a shower, rain and drought cannot be much affected by anything man can do. They are the result of world-wide, even cosmic processes, and are the product of the flowing of great streams of air, and the evaporation of millions of tons of water, at an expenditure of energy that is scarcely conceivable. Thus it has been calculated that, to provide the English countryside with its average annual rainfall, power must be expended at the rate of 333,333 horse power per square mile, day and night, throughout the year, and moisture has to be brought often from hundreds of miles away from mid-Atlantic.

Since it is the result of evaporation, rainwater in its natural state is the purest form of ordinary water, though it may contain dissolved carbon dioxide that it takes up from the air; also, thunderstorm rain may contain nitric acid from the oxides of nitrogen formed by the lightning. These dissolved acids play a great part in the weathering of rocks, and often granite is found to be pitted with a number of small holes, which are due to the fact that the acids in rain attack and dissolve the felspar of the granite, leaving the harder quartz. Softer rocks, such as sandstone, are very much affected in this way, and buildings made of these materials weather quickly, especially in towns, where the rain is often laden with acids derived from chimneys. Town rain is also inclined to be dirty from the soot and other solid particles in the atmosphere of such places, and it has been suggested that examination of the deposit often found in rain gauges would make an interesting hobby. Sometimes the matter brought down by rain is of a more romantic nature. From time to time, especially in southern Europe, there occur showers of so-called 'blood rain' which leaves red stains behind it, and which at one time was a source of great alarm to the superstitious. The sinister discolouration, however, is really due to nothing more alarming than dust, which has been carried by air currents from some desert.

The German peasantry have a proverb that when it rains while the sun is shining, 'the devil is beating his grandmother; he is laughing and she is crying'; but to most people the idea of sun and rain together recalls that most popular of the optical phenomena of the atmosphere, the rainbow, whose many-coloured arch

of light has called forth numberless tributes from writers ancient and modern, ranging from the graceful but rather sentimental lines of Moore beginning

> Erin ! the tear and the smile in thine eyes
> Blend like the rainbow that hangs in thy skies,

to the stately rhetoric of Ecclesiasticus xliii.:

'Look upon the rainbow and praise Him that made it, very beautiful it is in the brightness thereof. It compasseth the heavens about with a glorious circle and the hands of the Most High have bended it.'

The rainbow has also received the compliment of attention from some of the greatest men of science from Aristotle onwards, men such as Descartes, Newton, and one of the greatest of Victorian astronomers, Sir G. B. Airy. It was Newton who gave the 'geometrical' theory of the bow in its complete form, which shows how, when sunlight falls on a drop of water, some of the light entering the drop is reflected from the far side and comes out from the near side in a direction lying within 42° from the position of the sun. But that is not all the story, for the light also suffers refraction, being broken up into its constituent colours, the red rays being refracted least and the violet rays most; therefore, to quote Newton, 'The Rays which differ in Refrangibility will have different Limits of their Angles of Emergence, and by consequence according to their different Degrees of Refrangibility emerge most copiously in different Angles, and being separated from one another appear each in their proper Colours.' The result is shown in the diagram, which is Newton's. The limiting angle for red is about 41°; all the drops, therefore, on the arc AFB will send red light to the eye.

The limiting angle for the more refrangible violet is 43°, so all the drops in that direction (AEB) 'shall send the most refrangible Rays most copiously to the Eye, and thereby strike the Senses with the deepest violet Colour in that Region.' In the same way Newton explained the faint outer bow that often accompanies the brilliant primary like its ghost, only in this case the

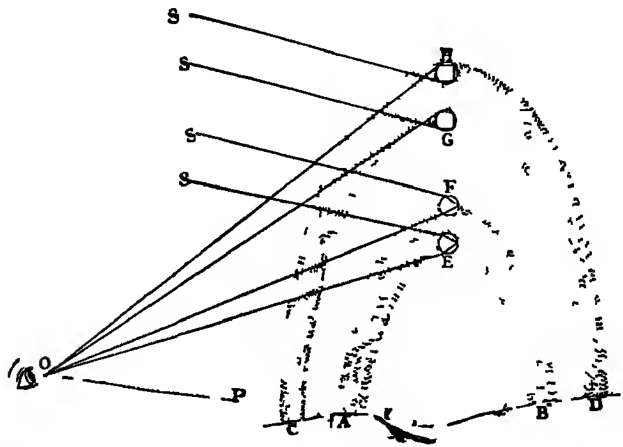


Fig. 8

Diagram of Rainbow (from *Newton's Opticks*, Bell)

rays of light are reflected twice instead of once, which is the reason for the faintness of this bow, and the reversal of the order of the colours.

But even this theory required some amplification, for it does not explain the coloured bands often seen inside the violet of the primary bow, nor the fact that bows differ amongst themselves in the width and brightness of the different coloured bands. The geometrical

theory says that there is only one direction in which the illumination is greatest, but in reality there are several, the result being that the actual bow seen is one due to the overlapping of several, and further complications are introduced by the fact that the sun is not a point of light but has a definite size, and that the drops of rain, even in the same cloud, are not uniform in size; indeed, through the calculations and experiments of Airy and Pernter it is possible to guess by inspection of a rainbow the approximate size of the drops. The most handsome bows in which the colours are purest are formed in the large drops of thundershowers, which are about $\frac{1}{25}$ inch diameter. With smaller drops, say about $\frac{1}{75}$ inch diameter, there is more overlapping, the colours being less pure, and 'spurious' bows occurring inside the violet, especially at the crown of the arch, for small drops are found chiefly at upper levels. And as the drops become smaller so the overlapping increases and the colours become weaker, till at last, with very small drops of $\frac{1}{500}$ inch diameter such as occur in fogs, the handsome rainbow has become the colourless fog-bow.

The fog-bow is the true white rainbow, for, though the name is often given to the pale bows that are formed by the moon, the only reason why these usually show no colour is because of the faintness of the light.

Very curious effects are sometimes produced when the sun is reflected in calm water behind the observer, for the reflected sun makes its own bows, which intersect those formed by the real sun. Another unconventional effect happened in 1937 at the Aldershot Tattoo, when several brilliant rainbows were produced

by the high-power searchlights that were turned on the arena to assist the exit of the audience during a shower, which bows are described as moving and interlacing in the most striking fashion.

The fact that the rainbow has a definite angular size accounts for the fact that it is less common in summer, when the sun is high, than in winter. When the sun's altitude is 42°, the top of the primary is on the horizon; as he sinks, the bow rises in the sky, till at sunset half is visible. From the air the complete circle is often seen, and one pilot is said to have had the experience of seeing the picturesque island of Corfu completely encircled by the brilliant colours of such a circular bow.

The drops that water the earth provide other wonderful sights for those who ride the skies. It is not uncommon for an airman to see below him a white, brilliant reflection of the sun, hanging apparently in empty space. The upper air at high levels is cold enough for any water vapour present to take the form of regular crystals, which sometimes are numerous enough to be visible as cloud. Often, however, their presence is only shown to the airman by the appearance of the reflected solar image, or 'undersun,' and to those down below by various forms of halo, that, especially in the polar regions, cover the apparently cloudless sky with the most fantastic and beautiful systems of rainbow and white rings, arcs, mock suns, pillars, and crosses imaginable. The frontispiece shows one such scene in the Antarctic; it was drawn by that true lover of the beautiful in nature the late Dr. E. A. Wilson who died with Scott. The name Paraselene is usually applied to the mock moons only, but it is sometimes used for the whole group of halo phenomena.

The accompanying sketch, Fig. 9, based upon a drawing of the earliest properly recorded halo (Rome 1630), shows some of the most usual forms, which also appear in ice-crystal clouds like cirrus and cirro-stratus.

A is the commonest form of halo, a ring of 22° radius (angular measure of arc: horizon to zenith 90°) which, when bright, shows more or less well-defined rainbow colours, with the red nearest the sun, for it is due to the refraction of light by six-sided crystals. It often has arcs of contact, which, when the sun is high, bend together to form the oval 'circumscribed halo.'

B is the less common halo of 46° radius, also showing colours with red to the sun. This is due to refraction by crystals with faces at right angles. The arc D which

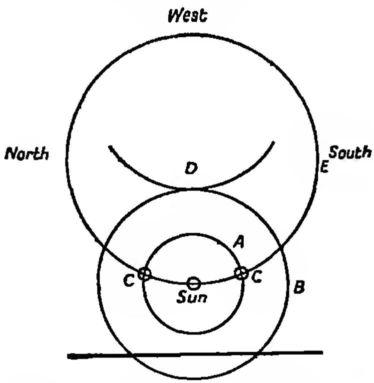


Fig. 9. Principal halo phenomena

touches its summit has been described as the most beautiful of all halo phenomena, for it shows such pure rainbow tints. If often appears by itself, and is due to prismatic crystals with their axes upright.

CC are the two mock suns or parhelia, well known to sailors as 'sun-dogs.' These are coloured images of the sun formed by prismatic crystals floating with their axes vertical at the same level as the sun.

E is the mock sun ring or parhelic circle, which, being caused by reflection of light from the upright faces of crystals, is white. Sometimes a portion of this circle appears at the same time as a white column of light through the sun (or moon), which is caused by the reflection of light from the under and upper surfaces of tabular crystals, the result being the appearance of that very striking and beautiful phenomenon, the cross.

When tabular ice-crystals float at fairly low levels in the atmosphere, the reflection of light from their under surfaces gives rise, not only to pillars of light above the rising or setting sun and moon, but, in countries like Canada and the U.S.S.R., over artificial lights as well, and once, during the war, to one of the most extraordinary spectacles ever seen. The date was November 6th, 1916. 'During the remainder of the evening,' writes the witness through whose kind permission this vivid account appears, 'gun flashes were focused into narrow vertical streaks centred about 10°–15° above the horizon.

'This made a most weird and unnatural effect, as if hundreds of fiery daggers were appearing and disappearing all round the eastern horizon. More wonders still were to come, however. A large red glow from a fire some 9 or 10 kilometres to east-south-east lit up the sky, and it again appeared as a vertical streak, very large and fiery, with a dark space at its centre. This centre was $32\frac{1}{2}°$ above the horizon. I

had plenty of time to measure it with the theodolite, and did so. Sometimes the streak separated into two, side by side, and it waxed and waned in intensity – apparently with the fire (or fires?). At 10.20 p.m. I saw and heard a terrible explosion (the first of several). A vast, round-topped cloud of smoke rose into the sky to a height of 8° to 10° and drifted slowly away northward on the wind. Soon after the "streak" seemed to be slightly obscured by an upward stream of some sort flowing along it like smoke waves. Then, long dark streams commenced to run obliquely up it, extending into the darker sky on either side. . . . The whole thing reminded one of the stories about the fall of Pompeii or the burning of Rome. Even so frigid a scientist as the Chemical Adviser said that it quite overawed him to see "the Angel Gabriel crossing swords with the powers of darkness" – i.e. the red streak crossed by the oblique dark streaks' (from *Q.J.R. Meteor. Soc.*, 1919).

In cold districts, such as Canada and the Polar regions, the crystals that form from the moisture of the breath, or from the exhaust steam of locomotives, are regular enough to give halo effects in natural or artificial light.

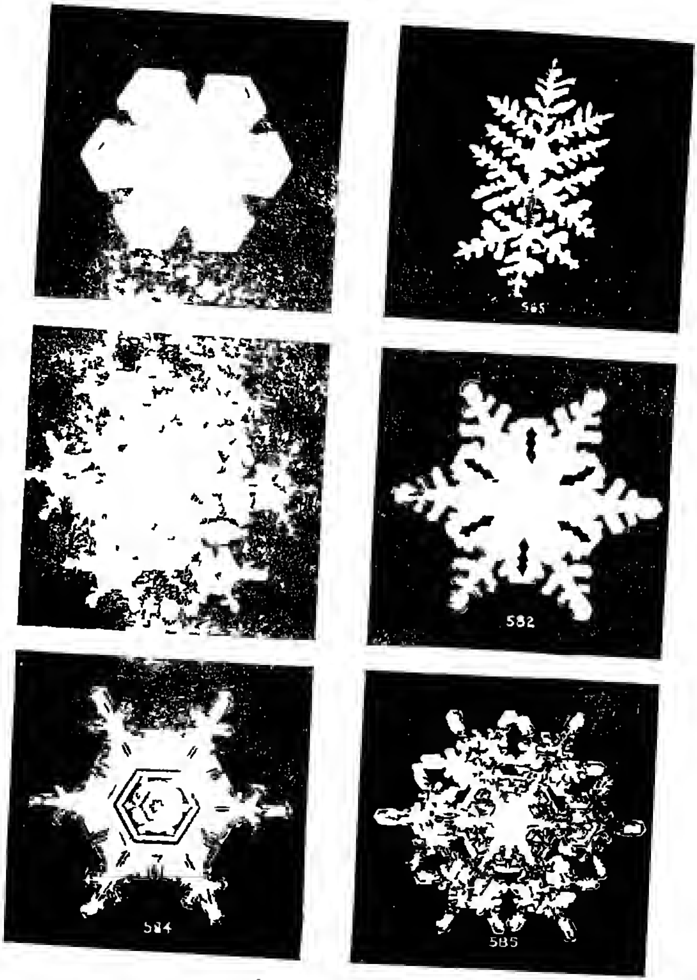
There are many other interesting and beautiful kinds of halo phenomena, which, however, cannot be described here.

Of the many forms under which water exists in the atmosphere, the snow-crystal is perhaps the most fascinating and the most mysterious. In the mild climate of Britain these crystals do not often develop to perfection, for, being formed at temperatures only just below freezing-point, they are moist, and fall matted together into flakes. Sometimes, however,

PLATE VII

Waterspout [illegible]

[illegible]



Snow Crystals

By courtesy of Messrs McGraw-Hill Publishing Co Ltd, from Bentley and Humphreys' 'Snow Crystals'

temperatures are low enough to permit of the formation of well-shaped, dry crystals, which fall singly, and may be caught on the coat-sleeve or a piece of black velvet. Some of the earliest drawings of these crystals were made by James Glaisher in 1855, but the chief exponent of the study of snow has been the late W. A. Bentley, of Jericho, Vermont, U.S.A. Living in a climate which favoured the formation of single crystals, he gathered a collection of nearly 5,000 microphotographs, among which there are no duplicates.

For the most amazing thing about snow-crystals is their individuality. Though they can be grouped into two main classes, columns and tables, the individual members of these groups show the most astonishing diversity of form, ranging as they do from plain six-sided plates and stars to shapes of the richest and most intricate design that appear more like the work of some master-craftsman than the result of impersonal laws of crystallisation (Plate VIII). Crystals occur in which one small star appears in the middle of a larger one. In many cases there is a flower-like design at the centre of the crystal, which, in one example, reproduces perfectly the familiar Tudor rose, the in-curvature of the petals being clearly visible.

There seems to be some relation between the type of crystal and the height and temperature of the cloud in which it is formed. Bentley found that the plainer forms, both tabular and stellar, were connected with very high clouds and zero temperatures, while the more complicated types were formed in medium or low clouds, particularly those in the front part of severe storms.

The formation of snow-crystals has also been studied

in the laboratory by watching the crystallisation of iodoform, which, like water, crystallises in six-sided stars.

During the crystallisation of snow a great deal of air becomes entangled in the rays, and it is the presence of this air which adds to the beauty of the crystals in photographs, since it shows up as dark markings. The air also makes snow very bulky, so that it is generally reckoned that one foot of snow is equal to one inch of rain, though the actual proportion depends upon the moisture content.

Nothing appears softer than snow, yet in large quantities it can exert an almost irresistible weight. Not only are trees and telegraph poles broken down, but roofs have been known to collapse under the weight of the accumulated snow. The ice of glaciers is nothing but snow compacted by the weight of the upper layers. In 1932 there was an unusually severe winter in the San Juan Mountains, Colorado, and the Animas Cañon, which is traversed by the railway serving the mining town of Silverton, was blocked by a series of snow-slides. The combined effect of the cold and the weight of the snow was to compact the slides into solid masses of green ice that turned the edge of a pickaxe. The only way to clear the line was for workmen to drill holes in the ice and pack them with explosives. After the charge was fired the engine on the relief train, which was fitted with a special steel-shod battering-ram, backed about 70 yards and charged the wall of ice. When this had been done three or four times, the ice was loose enough for the workmen to remove it in lumps, which were thrown into the gorge below.

On the Newhaven road, just outside Lewes, there is

a public house called the Snowdrop, which was built on the site of a great snowslide from the South Downs after the great snowstorm of 1836, which buried a row of cottages and caused eight deaths. Avalanches are common enough in the Himalayas and in Switzerland, in which country they do millions of pounds' worth of damage every year. Much of this damage is done by the wind caused by the displacement of the air in front of the moving snow. On one occasion, it is said, part of an iron bridge weighing several tons was thrown upwards about 150 feet; and the tale is also told of an Alpine diligence, complete with coachman and horses, being blown bodily across a stream by the blast from an avalanche.

There is no need to enlarge upon the hindrance caused by snow to all forms of transport, or to describe to a generation familiar with the stories of the hardships and heroisms of polar exploration the terrors of the blizzard.

But snow is helpful as well as harmful. In winter it forms a blanket over the earth which protects the vegetation beneath. The large amount of air entrapped in the crystals prevents the layer of snow from conducting heat, so the temperature of the soil remains quite uniform, however much that of the air may change.

And snow adds vastly to the beauty of nature. Not only are the individual crystals masterpieces of beauty, but, when in mass, their facets reflect the light and take on that spotless whiteness that is the crowning glory of the snow. No one who has had the opportunity can ever forget the first sight of the high snows, such as that of the shining double peak of Mont Blanc

as seen from Geneva. And the view of the white peaks of the Himalayas has inspired many, from the ancient Hindu who wrote:

'In a thousand ages of the gods I could not tell thee of the glory of Himachal,'

to the anonymous modern writer of

> He who hath seen the eternal snows,
> Noonday white and evening rose.
> Though he descend down to the plain,
> Never is the same again;
> And in the mud, the dirt, the sweat,
> Cannot lose, cannot forget,
> The radiance of the eternal snows,
> Noonday white and evening rose.

Sometimes when snow falls it has to pass through a layer of comparatively warm air. The result is the mixture of rain and snow called sleet.

Much rarer than sleet in this country, but rather important because of the interference it causes to transport, not to mention hundreds of minor accidents to pedestrians, is glazed frost. This is caused by rain which freezes as it reaches the ground, covering everything with a very deceptive layer of smooth, transparent ice. Glazed frost is quite well known on Dartmoor, where it has received the very appropriate dialect name of 'ammil,' which is derived from an old English word 'amel,' meaning enamel. Like many dialect terms, this is a most appropriate one, for branches, telegraph wires, and the like become coated with a smooth coating of ice, which looks fairy-like in the sunshine, but which often does a great deal of damage through the breaking down of branches and wires by the sheer weight of ice. In a severe glazed frost – or

'ice-storm,' as it is called in America, where such visitations are rather common – an ordinary sized tree may collect five tons of ice, and the amount carried by a small twig may be 130 times the weight of the twig alone, while the damage to property may run into millions of dollars. Glazed frost is also common on the Continent of Europe, and no description ever written could better the naive comments of the fifteenth-century Florentine apothecary, Luca Landucci, who described in his diary how on the night of January 17th, 1490, 'a certain fine rain' turned to ice as it fell, and how in consequence not only were trees damaged and haystacks roofed with glass, but 'it was too dangerous for anyone to walk in the country.'

Another not uncommon happening in this country during cold weather is the fall of what looks very like tapioca. Strangely enough, there is no regular English name for this, though it is recognised in some dialects, such as that of the old-fashioned fisherfolk at Hastings, who call it 'egger-nogger.' There are also special names for it in French and in German, but in dictionary English it has to be called by the not very satisfactory title of 'soft hail.' It appears to be really a kind of cross between snow and true hail, appearing to form when conditions inside a cloud are such that ice-crystals and super-cooled water-drops can exist together at not a very great height above the ground. If one of these super-cooled drops touches an ice-crystal it at once solidifies, imprisoning a little air. Then it begins to fall, reaching the ground as a lump of soft white ice.

Very different is the result if this process takes place inside a large thundercloud, which reaches to such a great height in the atmosphere that, even in summer,

the temperature at its summit is very low. The rising water vapour, which goes to make the cloud, is seized by the strong ascending currents of air, and some of it is carried so high that soft hail is formed. The pellets of hail then fall into a somewhat warmer part of the cloud, and are wetted; then once more the rising air currents seize them and carry them high enough for the water to freeze. After that has happened the hailstones thus formed may be tossed still higher and receive another coating of snow, and so the process may go on until the stones are heavy enough to fall through the rising air currents. When such hailstones are cut in half they are found to have alternate layers of snow and ice inside like the coats of an onion. One such stone, which fell at Annapolis, Maryland, on June 22nd, 1915, was found to have no less than 25 such layers. Very large stones can also be formed by the freezing together of hailstones in the air.

Tropical and semi-tropical countries are most afflicted by severe hailstorms. The great heating of the ground by the sun gives rise to very strong ascending currents. In some hot countries the temperature at the ground level is so high that hail very seldom reaches the ground unmelted. An amusing story is told of a native of the East Indies who was so astonished by a hailstorm that he collected a large quantity of the hail in a basket so that he could show it to his family. Unfortunately, by the time he had reached home the hail had melted and run away, so he had nothing to show in support of his narrative!

In many places, however, hail is able to reach the ground unmelted, and great damage is done to crops every year in America, South Africa, and even Europe.

Personal injury is not unknown; scarcely a year passes without reports from India, South Africa, or Central Europe of cattle and even human beings being killed by hail. In 1936, for example, nineteen natives in the Transvaal lost their lives in one storm. In view of such facts the account in the Book of Joshua (x. 11) of how a Canaanite army was discomforted by a hailstorm so that '. . . they were more which died with the hailstones than they whom the children of Israel slew with the sword' becomes perfectly credible, especially when it is remembered that the rank and file in those days wore no armour, and that hail often falls with force enough to riddle the roofs of taxicabs, and even galvanised iron. The hailstones, too, often are very irregular in shape, fairly large jagged lumps of ice being quite common. These no doubt are formed by the freezing together of several stones in the air. Even in this country serious damage may be caused by hail; in the great hailstorm that swept across mid-Essex two days after the Diamond Jubilee of Queen Victoria, in 1897, besides extensive damage to crops there was a regular massacre of game and poultry, one village losing 200 chickens, while several people who were caught out in the storm were beaten black and blue, and even felt hats did not save their wearers from receiving severe knocks. So great, indeed, was the loss caused to the farmers, who, with one exception, were not insured, that a Mansion House Fund of £27,000 was raised for their benefit.

The question of hailstorm insurance is a very important one on the Continent, where the peasants are great sufferers; and in Italy, of whose 40 million inhabitants 24 million live on the land, there is a movement to make such insurance compulsory. In this country those

who are very interested in such protection are nurserymen, for even a moderate storm can do a great deal of damage to glasshouses.

The drops that water the earth do not always do so as rain. When on an historic occasion Elijah pronounced the doom of Israel, he said, '. . . there shall not be dew nor rain these years but according to my word' (1 Kings xvii. 1). In the rainless summer climate of Palestine dew is vital for cultivation, and should it fail, as it did for 10 days in July 1916, great distress follows.

In the olden days it was thought that dew fell, an idea that gave rise to one or two poetic fancies. It was thought, for instance, that pearls were congealed dew; the oysters, it was believed, rose to the surface of the sea during the night and caught the dewdrops, which in time hardened into jewels. Research, however, has shown that dew is really moisture condensed from the atmosphere on surfaces exposed to the air, and only forms on clear nights, when the radiation from the earth is great enough to cool grass, leaves, etc., to such an extent that the air in contact with them deposits its moisture upon them, much in the same way that a cold pane of glass condenses the moisture of the breath.

The famous dewponds of the South Downs have received their name because it has been thought that they were replenished at night by dew. The mystery about them is that they do not dry up except in the most prolonged droughts, in spite of the watering of cattle, and more than one theory has been put forward, the most probable being that, being on high ground, they are less exposed to evaporation than ponds lower down; also they receive more rain, and, being artificial,

have watertight bottoms of about 9 inches of puddled clay or chalk treated with lime. Also the bottom is protected from being trampled by cattle by a layer of chalk rubble over the real bottom.

In cold weather the moisture of the air condenses as hoar frost. Incidentally, 'hoar' is the old English word for 'white,' and is used in contradistinction to a long spell of freezing weather without visible deposit, or a 'black' frost. Hoar frost is not frozen dew; the water vapour passes directly into the solid form and crystallises upon the grass and leaves in fairy-like crystals that give to the landscape in the early morning a delightful aspect.

Observations of Mars have shown that many of the ruddy 'continental' areas, when on the edge of the disc, i.e. experiencing their early morning or late afternoon, are as white as the poles with what must be a deposit of hoar frost.

But perhaps the most delightful frost effects are those that occur on windowpanes during cold weather, and cover the glass with trees and ferns and geometrical designs of bewildering variety. The most delicate patterns are those which arise from the crystallisation of the moisture of the air upon dry glass in an unheated room; the bolder and more striking effects are due to what Bentley called window-ice, as they form in the thin film of water that covers panes of warm, moist rooms.

The moisture in the atmosphere is never at rest. It floats invisibly in the air; it takes visible shape in the clouds; it falls as rain, hail, or snow, or is deposited as frost or dew; it may pass into the soil, thence to be drawn in by plants and given up by them to the

atmosphere, or it may find its way to some spring that feeds a river and thus make the journey to the sea, but sooner or later it returns to the atmosphere by evaporation, to go through the same cycle again and again, as Shelley realised when he wrote in 'The Cloud':

I am the daughter of Earth and Water
  And the nursling of the Sky;
I pass through the pores of the oceans and shores.
  I change, but I cannot die.
For after the rain, when with never a stain
  The pavilion of Heaven is bare,
And the winds and sunbeams with their convex gleams
  Build up the blue dome of air,
I silently laugh at my own cenotaph,
  And out of the caverns of rain,
Like a child from the womb, like a ghost from the tomb,
  I arise and unbuild it again.

CHAPTER VI

The Thunderstorm

Lear:

First let me talk with this philosopher,
What is the cause of thunder?

King Lear, iii. 4

About the time that lightning conductors were coming into general use, the French Abbé Poncelet wrote a curious book, the title of which may be translated as *Nature, in the Formation of Thunder and the Reproduction of Living Things*, in which he protested strongly against what he thought to be an undesirable innovation, and also expounded his idea that the force that produces the lightning is the same as that which causes the earth to fructify.

The abbé was not the first to have that idea. In many primitive religions the thunder god or gods are intimately connected with rain and the crops, especially in those lands which experience prolonged droughts broken by thunderstorms, after which the desert literally does 'blossom like the rose.' Thus, in ancient India, men worshipped Indra with his train of Maruts, beautiful youths clad in golden armour, who warred against the demons of drought with thunderbolts and spears of lightning; and, in Mexico, they believed in Huitzilpochtli, the serpent god of lightning who had power over the crops. And it was only about a generation ago that, in the heart of Australia,

the headman of the Yuin tribe told a traveller, 'Thunder is the voice of Him' (he pointed upwards to the sky) 'calling on the rain to fall and everything to grow up new.'

And both the simple savage and the learned abbé were wiser than they knew, for the thunder and lightning, that make a fully developed storm one of the grandest of natural phenomena, arise from the same cause as the heavy and often fertilising showers that accompany the storm, namely the copious condensation of water vapour. No thunderstorm can develop without two conditions being fulfilled; first, an adequate supply of moisture to feed the growing cloud (in this country below the 10,000 foot level), and second, a rapid enough fall of temperature with height, through at least two miles above the base of the cloud, to set up the necessary 'instability' in the upper air, without which, however great the quantity of moisture, a storm will not develop. That is why hot weather does not always bring thunder; the warm, fine spell may go on so long that the air may become warmed up top and bottom and 'stable,' so that thundery conditions cannot be set up. Indeed, conditions in the upper air influence the growth of storms so much that the forecasting of thunder and showers within 24 hours has been much improved since the Meteorological Office has been able to receive reports of temperature, humidity, etc., in the upper air from the Meteorological Flights of the Royal Air Force at Mildenhall and elsewhere. When received, these observations are plotted on a diagram called a tephigram, inspection of which enables an expert forecaster to determine with a fair degree of accuracy the chances for or against thunder-

storms. This method is especially useful in connection with flying, for which short-period forecasts are particularly in demand, and in summer-time, when the morning of a day on which a thunderstorm occurs looks as bright as that of a day which remains fair throughout.

Thunderstorms may arise in many ways.

The typical summer thunderstorm is caused by the same sort of process that results in the formation of cumulus clouds. The air in contact with the ground becomes heated as the day wears on, and rises, carrying with it water evaporated from the sea, rivers, plants, or even the soil. At a certain height in the atmosphere condensation takes place, and if there be enough moisture, and a great enough fall of temperature, huge cumulo-nimbus clouds will be built up. Storms of this kind are very common on summer afternoons, and it is through them that in some of the eastern counties July is the wettest month of the year. After forming, these storms often drift with the wind at their height, and sometimes storms that develop over France may cross the Channel to our south coast. It is in the tropics, however, that heat thunderstorms attain their greatest number and severity. Leon, in Mexico, is said to experience 143 a year. Batavia, in Java, is a good second with 133, while several places in tropical Africa and South America go over the hundred mark. Many tropical islands, too, experience regular storms from the forced ascent of air up the sides of mountains. Almost every day the clouds gather in the morning, the storm breaks in the afternoon, and the sky clears in the evening.

Thunderstorms may also arise from the passage of

cold air over a warm sea or land surface, and these storms, which are fairly common on our western coasts in winter, are generally slight. More important are those due to the meeting of air-currents of different temperatures and humidities, and it is the great contrasts in temperature set up over the Mississippi valley, when warm, moist air from the Gulf of Mexico meets colder air from the north-west, that not only produce violent thunder and lightning, but the most severe storm on earth – the American tornado. This is, to quote the eloquent description given by the late Professor R. de Courcy Ward to the Royal Meteorological Society, 'a very intense progressive whirl, of small diameter, with inflowing winds which increase tremendously in velocity as they near the centre, developing there a counter-clockwise vorticular ascensional movement whose violence exceeds that of any known storm. From the violently agitated cloud mass above there usually hangs a writhing funnel-shaped cloud swinging to and fro, rising and descending – the dreaded sign of the tornado. With a frightful roar "as of ten thousand freight trains" comes the whirl out of the dark, angry, often lurid, west or south-west, advancing almost always towards the north-east with the speed of a fast train (20 to 40 miles an hour or more); its wind velocities exceeding 100, 200, and probably 300 or more miles an hour; its path of destruction usually less than a quarter of a mile wide, its total life a matter of perhaps an hour or so. . . . A horse has been carried alive for over two miles. Iron bridges have been removed from their foundations. A cart weighing 600 lbs. has been carried up in a tornado, torn to pieces, and the tyre of one wheel was

found 1,300 yards away. Beams are driven into the ground, nails are forced head first into boards, cornstalks are driven partly through doors.'

Miraculous escapes continually take place. In 1929 the headmaster of a school in Virginia was in the school hall when the storm struck the building. The next thing he remembered was that he was standing knee deep in a pond 75 feet from where the building had been (an eye-witness saw it disappear before his eyes), shaken and frightened, but unhurt. In the same state the barn in which the farmer's sister was milking a cow was lifted up and carried away. The woman was found under a floor of the barn, which was resting on a stone wall some distance away; neither she nor the six cows that were in the barn was hurt.

One tornado has been known in five minutes to kill 250 people, and do damage to the amount of $15,000,000 (about £3,000,000).

Tornadoes are not confined to the United States, but are liable to occur wherever thundershowers can form, and are not unknown in this country. In 1931, for instance, Birmingham was visited by one. One person was killed and much damage was done to property, and in 1928 a small tornado crossed London from Victoria to Euston, doing damage estimated at £20,000. Again, waterspouts – the name under which tornadoes are known when they form over seas or lakes – are not uncommon in the Channel, though they reach their greatest development in the tropics. Under the whirl there is a great fall in atmospheric pressure, so the sea beneath a waterspout is much disturbed and may rise several feet; but large amounts of water are *not* drawn up into the clouds, as is sometimes thought,

and the water which falls from a waterspout is perfectly fresh, being the result of condensation. Though harmless where large vessels are concerned, waterspouts are quite capable of wrecking smaller craft, or at least doing a good deal of minor damage, such as the stripping and breaking of booms and other deck-gear (Plate VII).

Storms may arise from the meeting of different air-currents in many ways. If by chance a warm, moist current and a cold current should be flowing side by side, violent and extensive storms may break out in the moving area of instability that develops between the two currents. The struggle for mastery between the dry harmattan wind and the moist south-west monsoon that takes place at the beginning and end of every rainy season in West Africa gives rise to the storms, familiar to readers of the late Mr. Edgar Wallace's African romances under the native name of 'M'shimba m'shamba,' but which the white residents call tornadoes. They break suddenly with violent gusts of wind, sometimes reaching 70 to 80 miles an hour, a great fall in temperature, often amounting to 15° F., heavy rain, and intense thunder and lightning, but they lack the funnel cloud of the American 'twister,' and rather resemble the line-squalls of temperate regions, which, however, are connected with the passage of depressions, and happen throughout the year. Storms are very prone to break out ahead of the cold front, due to the flowing together of air-currents in the lower air, and also to falling temperatures up above. In winter, too, thunderstorms may develop in the cold air behind the front. In some cases this breaking out of storms takes place along a line 40 or so miles long,

with a formation of a straight roll of cloud, heavy rain, hail, or snow, and thunder and lightning. The thick cloud and the violent vertical disturbances of the air make these squalls very dangerous neighbours for aircraft. Fortunately their speed of advance can be forecast with considerable accuracy and pilots be enabled to avoid the disagreeable experience of one airman, who, after being lifted from a height of 400 to 2,800 feet in a minute and a half, experienced a huge downward bump. Local whirls often develop in a line-squall which may give rise to multiple waterspouts or tornadoes.

Very often, however, especially in winter, cold-front storms only develop enough energy to produce a single flash and peal, which none the less, because of its suddenness, is often very disconcerting. No doubt it was this type of storm that broke over Westminster Abbey during the coronation service of Stephen in December 1135, and so flustered Archbishop William de Corbeuil that he not only dropped the sacred wafer but forgot to give the King the kiss of peace and benediction.

On the other hand, some tropical storms of a kind common in West Africa and the West Indies can go on producing lightning, for four and a half hours, which has been described as lighting up the huge cloud from top to bottom. Whence comes all this energy?

Lightning has always attracted the attention of mankind, and various explanations have been given, some superstitious and some rational. Some of the ancient philosophers believed it was caused by the friction of the clouds or was due to emanations from the earth. The first to think of it as electrical seems to have been

Hawksbee, who in 1705 wrote, 'Sometimes I have observed the light to break from the agitated [electrified] glass in as strange a form as lightning,' but the first really definite statement as to the identity of lightning and the electric spark was the pensioner of the Charterhouse, Stephen Gray, who, in 1735, spoke to his sceptical colleagues of the Royal Society about 'this electric fire, which by several of these experiments seems to be of the same nature with that of thunder and lightning.' The Royal Society did not remain incredulous long. Eighteen years later the Copley Medal was awarded to Benjamin Franklin for his proof of the electrification of thunderclouds. Actually, the first practical demonstration was given by one of Franklin's disciples, the Frenchman Dailbard, on May 10th, 1752; Franklin's own famous kite experiment took place some weeks later.

For some time this kind of experiment became very popular, not only among scientists, but with the public. The demonstrations were not without excitement; a French experimenter, one de Romas, during one such experiment, carried out before a fashionable circle, secured in one hour about 30 sparks, 9 to 10 feet long, and several hundred having lengths of 7 feet or less. De Romas was once knocked down by a discharge. In England, the first director of Kew Observatory, Francis Ronalds, carried out a series of experiments at his house at Hammersmith. The loud reports that ensued greatly perturbed the neighbours, who said they would be killed by the lightning Ronalds brought into the house. Indeed, a few rats were electrocuted. The only human casualty from this kind of experiment was Professor Reichmann, of St. Petersburg, whose

collecting-rod seems to have been struck by lightning at the moment he approached it. A discharge leaped to his head and killed him on the spot.

But, though the identity of lightning and the electric spark was settled nearly 200 years ago, there is still some uncertainty as to how the requisite electricity is generated. Probably the most favoured theory at the present time is the one put forward by Sir G. C. Simpson, the Director of the Meteorological Office, who supposes that the electrification of thunderclouds is due to the breaking-up of raindrops by the ascending currents of air which are such a feature of thunderstorms. As the drops fall through the air-currents they are broken up, and in so doing become charged with electricity. As found experimentally by Lenard, this disruption of the water-drops leads to separation of positive and negative electricity, with the result that large electrical charges accumulate, which bring into being strong electrical fields, and, as soon as these fields become extensive enough, discharges begin. Sir G. C. Simpson's view is that the discharges are at first small and local, a view which has received confirmation from the observations of Dr. Linke, who, from the air, has seen miniature flashes, only 10 yards long, in growing cumulo-nimbus cloud. The important part rising currents also play is shown by the fact that the most violent lightning occurs when the rising currents are strongest, as shown by the presence of hail. To support hailstones, very strong upward currents are needed; it is estimated that stones one inch in diameter require an up-draught of 59 miles per hour.

An alternative theory, sponsored by Professor Wilson of Cambridge, supposes that, in an electric field, the

raindrops acquire opposite charges on their top and bottom halves, and, as they fall through the air, attract charged ions to their lower halves:

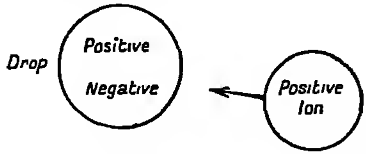


Fig. 10. The Wilson theory of thunderstorms

thus accumulating a net charge.

Recent investigations at Kew by means of sounding balloons equipped with recording apparatus have given results which, for the electric charges on the lower parts of the clouds, seem to support Simpson's breaking drop theory. But the investigations also suggest that the charges on the upper parts of the clouds, at levels where temperatures are well below freezing, are connected in some manner with the presence of ice-crystals.

There are some facts, however, that show that all lightning is not produced in either of these ways. 'Bolts from the blue' are no mere figure of speech; discharges have occurred under a starry sky, free from low cloud. Discharges have been seen to occur in cumulus cloud in which the observer was sure that drop formation was not taking place. And then there are cases like the extraordinary storm witnessed by Herr Knoche on the Paraguay River in 1927, when, after a seven months' complete drought, there was a most spectacular display of lightning, but not a drop of rain, and during the first six hours not a peal of thunder. All these instances show the great need for further research.

But however the generation of electricity may be accomplished, the result is to create very strong electrical fields between the cloud and the ground, or different parts of the cloud. The result is that, though air is a very bad conductor of electricity indeed, the electrical strain is so intense that, sooner or later, the resistance it offers to the passage of the discharge is broken down. This breakdown is not instantaneous. What seems to happen is that a local collapse of the insulating properties of the air begins in the cloud and burrows its way, so to speak, through the air towards the

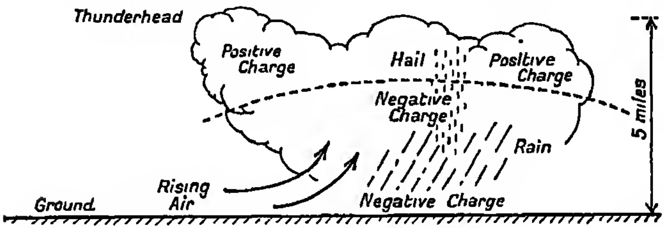


Fig. 11. Ideal section of thundercloud

nearest point of the opposing electrical field. As soon as contact is made, either with the ground, or with another part of the cloud, there is a great rush of electricity along the conducting path thus made for it, the outward and visible signs of which are the flash of lightning and the peal of thunder. The length of the discharge varies considerably, and when it takes place from cloud to earth it is seldom more than a mile, and often much less, especially in mountain storms. If the discharge is from cloud to cloud it may follow a much longer path, sometimes amounting to as much as 10 miles. The duration of the discharge is variable. It has been found that it may vary between $\frac{1}{2000}$ and

$\frac{1}{100}$ of a second. Moreover, investigations with moving cameras show that what seems to the eye to be a single lightning flash may be made up of five or more partial discharges. Recent researches in South Africa show that these partial discharges are often composite, each consisting of a downward stroke somewhat resembling a rocket, which is followed by a much brighter and faster upward stroke that develops rather like a flame.

The brightness of the flash is due to the intense heating of the air by the discharge. The colour varies considerably. Dr. Trabert, from his observations on the Sonnblick, Austria, considered that violet lightning was due to the discharge of negative electricity, and red to positive; but it has been found that in the spectroscope red lightning, in addition to the bright lines of glowing oxygen and nitrogen, shows those due to hydrogen, the strongest of which is the brilliant H_α in the red portion of the spectrum. White flashes, on the contrary, show the hydrogen lines faintly or not at all. The hydrogen, incidentally, is derived from the decomposition of water vapour in the path of the discharge, which, sometimes at any rate, breaks it up into its component gases. Red and yellow flashes are said to be common during the 'dry' storms of South Africa which occur before the rains have washed the air clean from the dust raised by the winter winds, and may be due to the absorption of light by the dusty atmosphere, for, once the dust has been laid by rain, white flashes appear.

These 'dry' storms are so-called because they are unaccompanied by rain. It is probable, however, that rain begins to fall from the cloud but is evaporated before it reaches the ground.

XLIX

H[illegible] cloud lightning, June [illegible] M[illegible] the flashes in this storm were of [illegible] great length [illegible] miles apart

[illegible]

PLATE X

Ball lightning observed at Lincoln, Nebraska, on August 30, 1930 (p. 155)

There appeared a [illegible] from [illegible] cloud which seemed to float slowly downwards

By courtesy of Professor J. C. Jensen, Department of Physics, Nebraska Wesleyan University, Office of the Chancellor, Lincoln, Nebraska

The actual appearance of a flash of lightning (Plate IX, p. 120) is too well known to need description. The branches, which give to so many flashes the likeness of the map of a river and its tributaries, are caused by the incessant changes in the electrical field at the end of the original conducting path, which result in its pursuing an erratic and ramified track on its way to make contact with ground or cloud.

An interesting but rather obscure development of ordinary lightning is the kind called 'pearl-necklace,' in which a flash is succeeded by a number of luminous points that lie along its path, often lasting for a couple or so of seconds.

One of the most beautiful forms of lightning is sheet-lightning or 'wild-fire,' of which most imposing displays are often seen at night. It is merely the reflection in the clouds of ordinary flashes, and it is frequently found, on inquiry, that a storm has occurred at some place in the direction in which the sheet-lightning was seen. Thunderclouds pile up to such great heights in the atmosphere that their tops can be seen at great distances; it is quite possible for a large cumulo-nimbus over the Bristol Channel to be visible from London.

Besides causing the air to become luminous, the passage of the electric discharge has other effects. The heating of the air starts a compression wave in the atmosphere that travels outwards in a pulse that affects the ear as the sound known as thunder. When the discharge takes place close at hand, a particularly vicious report is heard, but more often the sound is prolonged into a majestic rumble, which is due to the fact that sound takes different times to reach the hearer

from different parts of the same flash. The branchings and crookedness of the flash also have something to do with the variations in intensity of the sound, as may the fact mentioned above that lightning discharges are usually composite, consisting of several flashes following one another within a second or so.

Fig. 12. Zin-Shin, Chinese God of Thunder (from the *Buddhist Praying Wheel*, by W. Simpson; Macmillan)

There seems to be some difference in the nature of the sound according to whether the lightning is in the clouds or from clouds to earth, discharges in the clouds making a booming sound.

There is little doubt that it is the thunder that makes storms so terrifying to many people; indeed, some primitive people regard the thunder, not the lightning,

as the cause of fatalities, and the thunder god or gods is often equipped with means to make the noise; for instance, the Chinese deity, Zin-Shin, is represented as a strange yet not unbeautiful being, half man and half eagle, riding the heavens, and beating his circle of heavenly thunder-drums. The American Indians imagined that the 'thunder-bird' made the thunder by the beating of its wings; our own ancestors heard in the peals the rumbling of the chariot of Thor the Thunderer. The great part the 'bull-roarer' has played, and still plays, in the rites of primitive peoples is no doubt due to the extraordinary sound it makes when whirled, which is more like thunder than anything else. In Scotland it is called a 'thunnerspell.'

Since sound travels roughly at the rate of a mile in five seconds, the distance of a storm can be judged with fair accuracy by noting the interval between the lightning and the thunder, for the speed of light is so great (186,000 miles a second) that over ordinary distances it may be neglected. Thunder is seldom heard at distances over 10 miles, though cases of discharges being audible at 40 miles have sometimes been reported. There are several reasons for this, the chief one being that during a thunderstorm the atmosphere is not in a good condition for the transmission of sound. It has also been proved by observations from a balloon that sound is not able to travel downwards easily; thus the noise from flashes in the clouds and from the upper part of cloud-to-earth flashes does not carry well. Also, it is likely that not all the sound waves made by the discharge are audible, some of them being too long to affect the human ear, though they may make their presence felt through the rattling of windows.

In addition to thunder, lightning is sometimes accompanied by a curious 'vit,' or click, of which at present there is no generally accepted explanation. Lord Kelvin was inclined to connect it with the sounds emitted by condensers on being discharged and charged. A more modern suggestion is that it is due to an induced charge in a person's head escaping to earth at the moment of the flash and stimulating the auditory nerve.

Sometimes lightning strikes direct to the ground, and fused and pitted rocks are often to be found on mountains. Very often, however, it is attracted to the nearest conductor, and flows along with varying results. For instance, a good conductor like metal can take the flash quite well; indeed, a copper wire one-third of an inch in diameter can carry safely the current from the most violent of flashes, and that is why properly erected lightning-rods are such a protection. These conductors were introduced as the result of the studies of Benjamin Franklin, and became objects of great controversy. There were many heated discussions over the various aspects of the question, one burning topic being whether they should end in knobs or points. One of the staunchest upholders of knobs was no less an individual than George III, who tried hard to win over Sir John Pringle to his point of view. Sir John's reply was a masterpiece, since it combined both conviction and tact. 'Sire,' he replied, 'I cannot reverse the laws and operations of nature.'

Hot air is another good conductor, and that is no doubt the reason why lightning so often comes down the chimney. Much loss of life amongst cattle is probably due to the fact that, not only do they seem

more susceptible to electric shock than human beings, but that during storms they herd together in large groups from which rises a column of warm, moist air. In South Africa, especially during the season of 'dry' storms, lightning has been known to follow in the track of waggons which are drawn by large teams of sweating horses or oxen, and prudent farmers outspan at the first indication of a storm. The soot lining of chimneys is also a conductor.

Water is a very good conductor, a fact which explains the danger from lightning being less once rain has begun. A well-known Everest climber probably owed his life to his clothes being wetted by rain. During a storm in the Alps he was knocked out by a near discharge, but soon recovered. He was told afterwards by a scientific friend that had his clothes been dry he would probably have been killed, but, as it was, his wet condition enabled some of the discharge to pass to earth.

Wood is a bad conductor, and that is why the neighbourhood of trees is so dangerous during a storm. They attract the flashes but are unable to carry the full discharge, part of which passes to earth outside the trunk. An additional source of danger where trees are concerned arises from the damage done by the discharge. Many trees contain cavities, fissures, and the like, which are full of air; this air is heated by the lightning and expands with explosive force, splintering the trunk and wrenching off branches or stripping the bark. The old wooden sailing-ships suffered badly from lightning. Between 1810 and 1815 no less than 58 vessels of all kinds were damaged by lightning, and many tragedies took place; for instance, H.M.S. *Resistance* of 44 guns was blown up by a flash that reached the magazine.

In the days before lightning conductors, many terrible disasters took place, such as occurred in 1769 at Brescia, when lightning exploded some 80,000 odd tons of powder in the State arsenal. Churches also have suffered a good deal on account of their lofty towers and spires, and in this connection an experiment recently performed at the New York laboratory of the General Electric Company is not without significance. The scale model of a village was subjected to one of the 2,000,000-volt discharges which the company's generating plant enables them to produce. The photograph taken on the occasion of this experiment showed that, though the main discharge went fairly straight to earth, the steeple of the model church attracted a portion of the spark.

Intensive research into lightning is especially urgent in America, not only on account of the thousands of miles of overhead electric cables, but also because of the lofty skyscrapers and the great oil-fields, where the results of a lightning stroke can better be imagined than described. For instance, one such fire at San Luis Obispo resulted in the destruction of 6,000,000 barrels of oil. The General Electric Company has truly magnificent laboratories, equipped with apparatus such as three giant transformers, which are wound with 100 miles of wire and earthed in a tank containing 40,000 gallons of oil, which can step up the current to 2,000,000 or 3,000,000 volts, an electrical pressure which gives sparks 5 yards long and which is used to study the effect of lightning discharges on transmission lines, telegraph poles, etc. Recently the company has opened a lightning observatory on a site commanding extensive views and fitted with a 12-lens

revolving camera and other modern apparatus. Research is also being carried on in this country at the National Physical Laboratory and at the works of Messrs. Ferranti Ltd., where miniature lightning is also produced and studied.

But, despite all these mechanical advances, it must be admitted nature is still far ahead, for, with no more complicated means than water-drops and rising air-currents, a really vigorous storm can produce several flashes a minute. For instance, 6,294 were recorded in six hours during the great London thunderstorm of July 9th, 1923, and 50 flashes a minute for three hours on end were recorded in an Abyssinian storm. Indeed, Professor W. L. Bragg has estimated that an average thunderstorm works as hard as 10 power stations of the size and capacity of that truly magnificent example of engineering enterprise, the great works at Battersea.

There seems no limit to the effects of lightning. Persons struck by lightning often declare they felt themselves knocked out by a tremendous blow; this has been shown by Sir Oliver Lodge to be due to the compressed air driven in front of the discharge, which hits so hard that it often hurls the victim several yards. The discharge not only, as mentioned before, decomposes the water vapour in its path, but it makes the mixed oxygen and nitrogen of the air to enter into chemical combination as one or other of the oxides of nitrogen, gases which are probably responsible for the smell of 'sulphur' that often hangs about places struck by lightning. In the presence of water vapour, nitric acid is also formed. It is estimated that 250,000 tons of this are produced every day in the many thunderstorms that are always going on somewhere or other.

The advent of wireless has also revealed other results of the 3,000 kilowatt hours let loose in a flash of lightning: some of the energy goes to make the electromagnetic waves that interfere so much with the broadcast programmes. The study of these atmospherics has become an important branch of science; with the aid of instruments such as the cathode ray direction finder, in which a luminous line on a compass dial shows the direction from which the particular atmospheric reached the receiver, it is possible not only to locate thunderstorms, but in many cases to follow them across country for hundreds of miles (Fig. 13).

As regards personal safety in storms, though the danger in this country is not very great, a few remarks may be of use. There is practically no risk indoors, and many of the deaths out of doors could be obviated if trees, especially tall and/or isolated ones were always shunned. It is also recommended that wire fences should be avoided, for, if struck, they become dangerously charged throughout their lengths. The carrying of agricultural instruments, such as forks, point upwards during a storm is inadvisable, and the same remarks apply to guns; many accidents have happened to soldiers because of this. Since lightning always takes the shortest possible path, the crest of a hill is dangerous. It is a tradition at Southwick, near Brighton, that Thunderbarrow Hill, rising 500 feet above the village, gathers the lightning to itself. During the summer months, watchmen are stationed by the Canadian forestry authorities on mountains in the Rockies to keep a look-out for possible fires; their huts have to be most elaborately protected against lightning, and the ground round is pitted by the discharges.

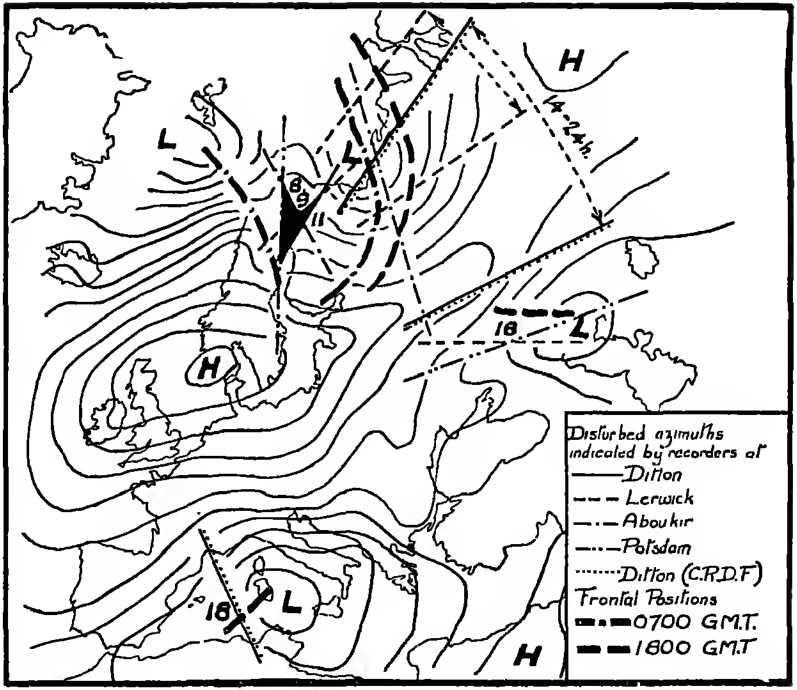


Fig. 13. Location of sources of atmospherics by direction-finding. Simultaneous bearings from two or more observatories are plotted on a map; the centre of disturbance is where the lines intersect. In the figure only the far ends of the lines are shown, but the particular observatory concerned can be identified by reference to the key. If the current weather is plotted on the same map it is shown that atmospherics emanate from regions of disturbed weather, such as the 'fronts' of depressions, L, and avoid the more settled high-pressure systems, H. (*Q. J. R. Meteor. Soc.*, 1929.)

In recent years there has been much investigation into the danger to aeroplanes and airships, and the conclusion has been reached that, though there is a certain amount of risk, cases of machines being struck are not common. It is recommended that a trailing aerial should be wound in at once when a storm threatens, otherwise there is the chance of the wireless set being destroyed and other damage done. To the writer, one of the chief risks seems to be the possible result of the disturbance to the personnel; at the inquest following a crash the opinion was expressed that the accident happened because the pilot's attention had been distracted by the fact that the plane had just been struck by lightning, so that he got nearer to the ground than he was aware.

Personal injury by lightning arises from various causes. There is the blow caused by the compressed air in front of the flash. Then the shock causes unconsciousness and stoppage of breathing through anæmia of the brain and medulla (which contains the respiratory centre), owing to the contraction of the arteries. The heart also contracts suddenly, as do the muscles of the limbs. The principal thing to do is to begin artificial respiration as soon as possible, for the pressure on the chest drives blood from the lungs back into the heart, and, if there is any life at all left in the patient, sets it beating again.

It is a fact that cannot be too strongly underlined that dozens of lives have been saved through prompt and patient treatment of this kind, though sometimes the artificial respiration has to be carried on so long that relays of workers become necessary. After breathing has begun, the patient should be watched for some time in case there is a relapse.

Much distress is often experienced by those struck by lightning through the cramps caused by the violently contracted muscles. These can be relieved by rubbing the limbs upwards.

Some treatment for shock is also necessary, and prevention of chill is particularly urgent in the case of lightning stroke, for the discharge generally relieves its victims of most of their clothes. The sudden heating of the air in the fabric makes it expand so suddenly that garments and boots are blown off the body. The momentary contact of the hot air with the skin also gives rise to superficial burns, which in severe cases cause markings so like foliage that at one time it was thought they were actual 'photographs' of trees. Other burns often occur below any metal objects such as coins, keys, badges, etc., carried on the person.

It is not at all uncommon for lightning to fuse metals. The discharge also magnetises steel objects and frequently upsets compasses.

One of the most prevalent ideas is that something solid falls to the ground in storms, and there are many people in the south-eastern counties who believe that the nodules of iron pyrites that are found in chalk-pits are thunderbolts. Such a belief has been encouraged by the fact that when lightning strikes into sand, tubes of fused silica are left behind; also, when a haystack is struck the silex from the grass-stems may be melted and run together in a large lump. There is also the fact that, to the uninitiated, the noise and flash of light that accompany the fall of a meteorite are indistinguishable from thunder and lightning. And then there is the reaction of the primitive mind to a thunderstorm so ably described by the late Dr. Jane Harrison in

Themis. She tells how the savage '. . . sees the black cloud rising, he feels a horrible oppression in the sultry air, he hears unearthly rumblings and watches flashes of lightning play across the sky. Finally he hears a noise over his head like a cartload of bricks; earth and sky, as Hesiod describes it, are jumbled together with an unspeakable din, and he gives up all for lost. Presently it is all over, the sun shining, the trees glistening, the earth refreshed and glad. If that were all, he might think there had been "plenty devil about" or, if he were an optimist, much "mana" and Wa-kon-da (magic force). But when he goes into the bush he finds a great tree split and charred, or the body of his best friend lying on the road dead, distorted. Something has struck the tree and the man and smashed them. . . .'

The Greek word for 'thunderbolt' – *keraunos* – comes from a root meaning 'to smash,' and the idea of this mysterious object permeates classical art and literature, as will be found in Hesiod's fine description of a thunderstorm:

> Turmoil and dust the winds belched out, and thunder
> And lightning and the smoking thunderbolt,
> Shafts of great Zeus.

And it is no doubt owing to the influence of classical models on art and poetry that the idea of the thunderbolt has persisted into modern times. That most modern of service decorations, which is barely twenty years old, the Distinguished Flying Cross, incorporates a thunderbolt in its design. Moreover, languages derived from Latin, such as French and Italian, follow the classical tradition in having three names for thunderstorm phenomena – thunder, ordinary

lightning (*éclair* and *lampo*), and destructive lightning (*foudre* and *fulmine*). These latter terms are also applied to certain phenomena of storms which must have done much to encourage the thunderbolt idea, and in English are known by the rather inadequate name of ball lightning (Plate X, p. 121).

From time to time during thunderstorms, especially in winter, there appear luminous balls, ranging in size from nuts to footballs, or larger, which sometimes disappear quietly, and sometimes burst with a loud report. Sometimes they fall from the clouds, but often they suddenly appear floating in the air or resting upon some good conductor like a wire. This latter type of ball is generally white and heats the surface to which it clings. The floating balls are red in colour, and drift about as if wafted by air-currents; they seem to be attracted by enclosed spaces such as rooms, which they often invade at the most inopportune moments. During a bell-ringers' service at Selby Abbey one rolled up the aisle and burst, leaving behind it the odour of 'sulphur' – in other words, that of oxide of nitrogen. Again, a fireball is recorded to have come in a bedroom window, circulated round the room, and then gone to the bed, singeing the hair and night attire of a lady. Sometimes these balls appear in closed rooms, though whether they are formed on the spot or enter through crevices is not certain. Of this sort appears to have been what must be one of the earliest recorded instances of a fireball. It is said that when St. Martin, Bishop of Tours (died 401), was saying mass, a ball of fire appeared in the air over his head and then rose heavenwards. Again, members of a tea-party at a house in Newcastle were astonished to see, after a clap

of thunder, a fireball lying on the ground near the door.

There have been many theories advanced to account for this strange phenomenon, but none is entirely satisfactory. At one time many scientists refused to believe that there was such a thing, even the great Faraday declaring, 'There may be balls of fire but they are not electrical.' There is one school of thought which regards ball lightning as being material and made of nitric oxide, but that opinion is not universally held, and many there are who regard these mysterious globes as something for which, at present, there is no explanation.

This being so, all the information that can be collected about the behaviour and appearance of fireballs is very welcome, and, as no special apparatus is required, the observation of ball lightning is one of the ways in which amateurs can be of real service to science. Investigators, however, are advised to confine their inquiries to eye observations, for Flammarion relates that, after an inquisitive child had touched a ball, there was a frightful explosion, the child and another were thrown down, and 11 head of cattle killed in the stable.

Ball lightning does not last for very long, three to five seconds being a usual duration, but it has been known to appear on an object and remain there for some time. Thus a New Zealand observer saw a bright white ball that stayed poised on a kind of finger that rose from a cloudbank for 15 minutes, and the British Consul in Hamburg once saw a purplish ball hovering over the copper-covered steeple of a church. This form seems to be on the way to become another famous kind of electrical discharge – St. Elmo's Fire.

Even in fair weather there is always a certain amount of interchange of electricity between the earth and air, the discharge tending to take place from pointed objects. In the normal way this is not strong enough to be noticeable, but when the electric tension rises, owing to thundery conditions, it often becomes visible. It has been known for centuries in the Mediterranean, first as Castor and Pollux, and then in Christian times as St. Elmo, after the martyred Bishop of Gaeta. The Portuguese called it Corpus Sancto, which has been corrupted by British sailors into Corposant or Comozant. It has received a niche in English literature, for on some description of St. Elmo's Fire Shakespeare must have based the speech in which Ariel tells Prospero how he boarded the king's ship and

> Flamed amazement; sometime I did divide,
> And burn in many places; on the topmast,
> The yard and bowsprit, would I flame distinctly,
> Then meet and join.

St. Elmo's Fire is not confined to the sea. There are many accounts of it appearing on the spears of soldiers, and one cavalry officer has described how, during the South African War, he was returning to camp with his squadron one night and the fire appeared, not only on the tip of every lance, but between the ears of his horse. Lightning conductors not only hiss alarmingly in strongly electric conditions of the atmosphere, but are often tipped with flames. A particularly amusing instance is mentioned by the French astronomer Arago; on January 14th, 1824, a thundercloud passed over a waggon loaded with straw, and the straw stood on end and became luminous!

But some of the finest displays are witnessed on

mountains. Those familiar with Wagner's operas know how much inspiration he derived from thundery weather, not only for his music but for his stage settings; indeed, it is these elaborate meteorological stage directions that make the production of his works so difficult, for what stage manager can deal adequately with the clearing storm and rainbow at the end of the *Rhinegold*, or the scene on the Valkyries' rock with the 'ever-darkening' thunderstorm coming up at the back, to denote the angered approach of Wotan? But even the imagination of Richard Wagner failed to appreciate how weird the scene would be when the storm did arrive. About three years after the first production of the *Ring* cycle in 1876, some tourists on the Gross Glockner mountain in the Tyrol were caught in a thunderstorm. After a blinding flash of lightning, they discovered St. Elmo's Fire streaming from their hats, beards, and clothes, while a neighbouring pine-forest was also literally blossoming with flame. Similar displays are very common at mountain observatories, the instruments, the tips of the rocks, and the head, hands, and pencil of the observer being decked with brushes of light. This appearance of the glow on the person is of interest in connection with the ancient Greek legend that the first time the Fire was seen was on the heads of the Heavenly Twins, Castor and Pollux, during a storm.

Some of the most valuable observations on the Fire have been made at the mountain observatory of the Sonnblick, in Austria, by Dr. Trabert, who found that the nature of the discharge varied according to the kind of electricity being discharged, the positive kind being in streamers about four inches long, while the

negative Fire envelops objects. It was probably this kind that appeared on the aeroplane of the late Sir Charles Kingsford Smith during his historic flight across the Tasman Sea in 1928, for bands of light encircled the propeller tips, disappearing when the electric tension was relieved by a flash of lightning and then gathering again.

Strong electrical fields are also raised by dust storms and drift snow. During the expedition of Sir Douglas Mawson to Adelie Land some 20 years ago, the snow carried by the strong winds of that region set up such strong electrical fields that not only was St. Elmo's Fire very common, but the apparatus set up to record the discharges sparked vigorously, and a bell attachment installed to attract the night watchman's attention to any particularly strong current passing through the recorder rang so continuously that it had to be dismantled as a public nuisance to sleepers!

St. Elmo's Fire has also been suggested as the cause of the mysterious apparition in the Gulf of St. Lawrence known as the 'Burning Phantom Ship of the Baie des Chaleurs,' one of the best descriptions of which was given a century ago by the Abbé Ferland, the noted French Canadian historian, who says, 'A bluish flame rises at times from the sea, halfway between Caraquet and Paspebiac. Sometimes as small in size as an ordinary torchlight and at other times appearing large and extended as a vast conflagration, it will advance, recede, or move upwards. When the mariner thinks he has reached the spot where he saw it, it suddenly disappears, only to reappear when he has moved away.' The local fishermen call this appearance, of the reality of which there can be no doubt, the 'bad-weather fire,'

as it is often seen before a storm, a fact which rather favours the theory of an electrical origin, though why it should so closely resemble a sailing-ship in flames is another question.

To some form of electrical discharge like St. Elmo's Fire have also been attributed certain luminous phenomena called 'Andes lights,' from their frequent occurrence in that range, where during the warm weather it is not uncommon to see the peaks lit up not only with a steady glow, but with great beams of light that shoot up to such heights that they are visible not only along the coast, but for miles out to sea.

CHAPTER VII

Weather

> 'When two Englishmen meet their first talk is about the weather.'
>
> SAMUEL JOHNSON

There are probably few harder worked words in the English language than the one which forms the heading of this chapter, and yet at the same time there are few words more difficult to define. Everyone knows what weather is, and yet finds it hard to put into words exactly what is meant by it. Even the greatest of English dictionaries can produce no better definition than 'the general condition of the atmosphere (at a given place and time) in regard to heat or cold,' etc., etc. Perhaps the best attempt, however, that has been made to express this elusive meaning is in a saying attributed to a bygone Professor Wilson, the gist of which is that weather is the mood of the atmosphere.

The moodiness, or otherwise, of the atmosphere varies from place to place. The Mediterranean peoples have no special word for weather, but have always used expressions that can also mean 'times' or 'seasons,' a custom no doubt originated by the regular sequence of atmospheric happenings in that region, where a dry summer with occasional storms is succeeded by a winter with capricious rainfall and sudden gales. The word 'weather' does not occur at all in the original text of the

Bible, all of which was written in lands enjoying a Mediterranean climate. In the Greek version of our Lord's reply to those Pharisees who asked of Him a sign from heaven, the word rendered 'fair weather' is the conventional Greek one for that state of affairs *eudia* – the favour of God; and that translated 'foul weather' is the Greek *cheimon*, which, significantly, can mean either 'winter' or 'tempest.'

But the Greeks had some experience of the moods of the weather, and their philosophers contrasted the steadfastness of the sun and other heavenly bodies, with the apparently disorderly behaviour of the thunder, rain, clouds, and wind in the lower regions of the *aer* (a name from which our word 'air' is derived), the realm of mists and cold. To-day there are many scientists who hold that there is a certain element of chance in the motions of the atmosphere; but even those would agree that modern research has shown that there is some system, even in the fickle climate of these islands.

In the preparation of the maps upon which the weather forecasts, now made in every civilised country, are based it is found that the distribution of atmospheric pressure, wind, rain, and other conditions, is not haphazard, but follows some more or less definite plan. Thus the isobars – imaginary lines connecting all the places where the barometer stands at the same height, showing that there the atmospheric pressure is the same – are usually arranged in one of seven quite definite forms, namely:

The Depression, with its modifications, the secondary and the 'V.'

The Anticyclone.

The Wedge.

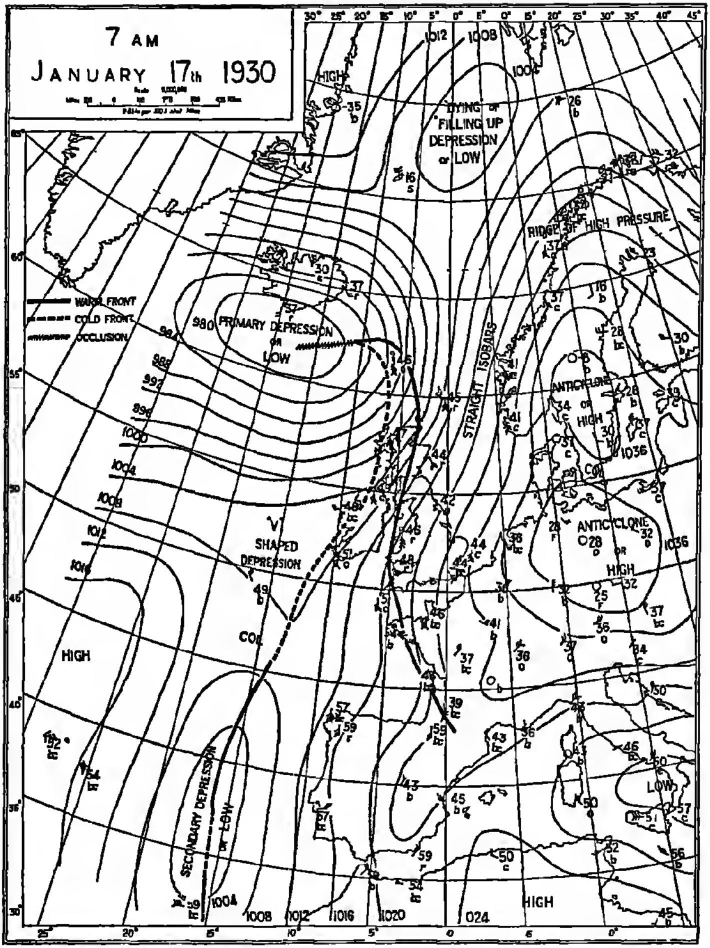


Fig. 14. Weather map showing seven chief forms of isobars

(The above Weather Map has been reproduced by permission of the British Standards Institution from British Standard No. 185 – 1933 Glossary of Aeronautical Terms.)

The Col.

Straight Isobars.

Of these forms, examples of all of which are given in Fig. 14, the most important and intriguing, from a scientific point of view, is the depression; indeed, some authorities regard the question of the origin and travel of this particular weather system as the main problem which meteorological science has to solve.

The depression is a region of the atmosphere where the pressure is lower than in the surrounding parts, more or less circular in shape, and varying greatly in size from 100 miles across to 2,000. A typical depression has been known to extend from the mouth of the Loire to near the Arctic Circle, including in its bounds these islands, Denmark, Holland, and Belgium, not to mention portions of France, Germany, and Scandinavia.

Depressions not only vary among themselves in size; they vary greatly in depth, some being shallow, with little difference between the readings of the barometer at the edges and in the centre, and some being very deep, with the barometer standing an inch or more lower in the centre than on the outside. These deep depressions are often associated with strong gales, owing to the strong pressure gradients, for the winds that circulate round the isobars, in the northern hemisphere in a direction opposite to the hands of a clock, and in the southern in the reverse direction, blow with a strength which is closely connected with the gradient or difference in pressure over a given distance. Depressions also vary as regards movement, some being nearly stationary, while others move at speeds up to 25 to 30 miles an hour. In speaking of

the movement of a depression, it is important to remember that there is little or no bodily transference of the *same* masses of air; what moves is the system of atmospheric circulation, air being continually drawn into it and expelled as it travels along. In this it is like a wave in the sea, as may be seen by watching the motion of boats; there is little movement of the particles of water, what travels along is the wave form.

As the depression moves along, it carries with it its weather, and many of the really reliable popular weather proverbs owe their validity to their being connected with the sequence of events as a depression travels over a place.

One of the first signs of an approaching depression is the arrival from a westerly direction of large quantities of cirrus clouds travelling at a great speed, hence the sailors' rhyme:

> Hen-scarts and filly-tails
> Make lofty ships carry low sails.

Green colouring in the sky at sunset or sunrise is also a common sign of approaching bad weather. On coasts, especially those with a southerly or westerly aspect, there are frequently heavy swells which have outrun the storm. The wind begins to back from its usual westerly direction to south or south-east.

> When the wind veers against the sun,
> Trust it not, for back it will run.

As the depression advances, the cirrus thickens to cirro-stratus, in which appear haloes round the sun and moon; thus there is the saying

> The moon with a circle brings water in her beak.

This prognostic is not infallible, as haloes appear in other circumstances, so it should be taken in conjunction with other signs, such as a falling barometer, etc., and the replacement of the cirro-stratus by alto-stratus, through which the sun and moon shine pale, giving rise to such sayings as the Arab:

'Trust not the horse if it is frisky nor the sun if it turns its back' – i.e. looks pale or hazy.

By this time the glass is falling and the air becoming damp and muggy, a condition of things which gives rise to various popular signs. As mentioned in many local sayings, some of which have been quoted in a previous chapter, cloud caps appear on hills. The increasing moisture causes certain flowers, like the pimpernel, to close. The atmospheric conditions also cause old wounds and rheumatic joints to throb, and make animals and birds somewhat restless, a fact that is no doubt behind the time-honoured nautical tradition that when the ship's cat is unusually frisky she 'has a gale of wind in her tail.' On land, the pig is credited with being able to 'see the wind.' As the Galloway rhyme has it:

> Grumphie smells the weather,
> An' grumphie sees the wun',
> He kens when the clouds will gather
> An' smoor the blinkin' sun,
> Wi' his mou' fu' o' strae
> He to his den will gae.
> Grumphie is a prophet,
> Wet weather we will hae.

Soon after the appearance of the alto-stratus, drizzle begins to fall, which is succeeded by driving rain from low nimbo-stratus. Then, sooner or later, the trough

or deepest part of the depression arrives, its passage, especially in the southern half of the system, being marked by a squall in which the wind may veer somewhat suddenly from south-west to north-west, a heavy clearing shower, and the upward turn of the barometer.

> When rise begins after low,
> Squalls expect and clear blow.

The wind not only changes its direction, but its character, for, instead of the muggy damp sou'wester, the north-westerly wind is cold and dry, hence the saying:

'Do business with men when the wind is in th north-west.'

And, since depressions are apt to travel in gro after the other it is said:

'A nor'wester is not long in debt to a sou

Soon after the passage of the trough, pa appear in the sky, giving rise to the nauti fine weather is coming when there is e the sky to 'make a sailor a jacket,' or, Dutchman a pair of trousers.' Somet idea is behind the more refined Roma that when there is enough blue in the Lady a cloak, then it is going to be fi clouds in the rear of a depression are ha from which fall occasional showers a very pretty skies.

The weather-changes described which take place when the centre of it often does, passes to the nort Should the reverse take place, a anyone in Scotland when the cen of the country, or in the British I

depression comes up the Channel, the wind would back through north, there would be rain with (actually through) a north-east wind which would back to the north-west.

During the past 90 years much attention has been devoted to the study of these depressions. In 1833, Luke Howard, the 'Father of Meteorology,' pointed out that rain could be caused by a cold northerly current of air pushing sideways under a warm southerly one, and similar ideas were expressed by Admiral FitzRoy and others. However, the theory of the
ression that really held the field from 1850 onwards
that this kind of weather system was caused by
eating, which set up a warm rising column of
ghtness of which created an area of low pres-
base. Round this low-pressure area it was
ind circulation was set up, and so a depres-
n. But soon after the introduction of
ons it was found that this kind of theory
for the records of conditions in the
by these balloons showed that the low
essions, instead of being confined to
nded right up through the atmosphere
the stratosphere, a matter of five miles

was therefore required, and the idea of
etween warm and cold currents of air
Professor Exner of Vienna, and Pro-
of Bergen and his son, whose views
y adopted, not only for their intel-
the practical aid they can give
ting the weather, that a short

According to Professor Bjerknes, depressions are the battleground of two sets of air-currents, warm and cold – or tropical and polar, as they are termed. Depressions are thought of as arising at the boundary between these two sets of air-currents, or 'polar front.' The two currents begin by flowing side by side in roughly opposite directions. Very soon, however, a bulge develops on the side towards the pole, the tropical air pushing up into the polar, which bulge grows larger and larger, its growth being encouraged by the fact that the polar air, by flowing round at the back, helps it to push out farther. At the tip of the bulge, according to the Bjerknes theory, the centre of the new depression is formed, which is carried with the bulge as it travels north-eastward along the polar front.

There can be no doubt that this theory helps to explain much of the characteristic weather of depressions. As warm air is lighter than cold, at the points where the two air streams meet the warm air rises over the cold and the cold pushes under the warm. The point where the warm air rises over the cold is called the warm front, which slopes forward gradually from the ground to a point some five miles high, several hundred miles in front of the centre of the depression, thus giving the whole sequence of cloud from the high cirrus of the outside to the low rainy nimbus near the centre. The muggy, cloudy weather in which, however, little rain falls, which is experienced in some depressions, is due to the warm sector where the warm air touches ground level (Fig. 15*a*).

In the same way the conditions at the cold front explain the great difference of weather between the front and rear of a depression. At the cold front, warm

air is not rising gradually over cold; it is being thrust rather forcibly upwards by the undercutting stream of polar air, hence the violence of the 'clearing shower' and the fact that this is often accompanied by hail and thunder. From the polar air, too, comes the coolness and briskness of the wind in this part of the depression, and the clearness of the air. Landscapes seldom look better than when seen through the clean polar air at

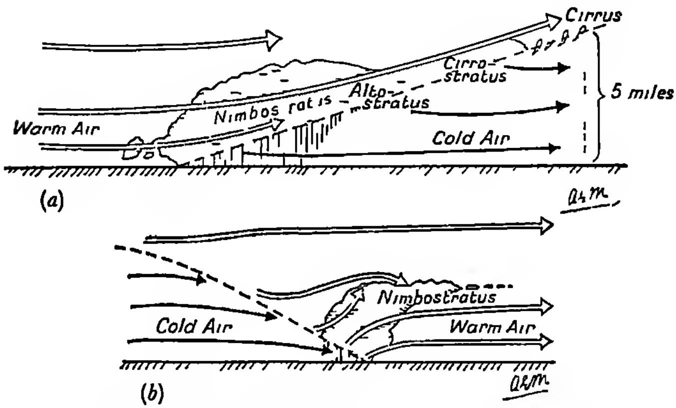


Fig. 15. The Bjerknes theory of the depression

the rear of a depression, under skies flecked with cumuli, whose picturesque rocky summits show the presence of the vigorous upthrusting of air (Fig. 15*b*).

Such is the sequence of weather in the southern half of the ideal Bjerknes depression. Actually conditions often diverge greatly from the pattern. For instance, by the time depressions reach these islands they are often dying and have become occluded – that is, the cold front has encroached upon the warm sector, reducing it first to a mere line, and then lifting it right

off the ground. Then, too, in their passage across land and sea the various air streams may change their characteristics. This is shown by the way the cold bracing polar air becomes the rather mild and damp maritime polar air by crossing the warm Atlantic.

Again, too, some depressions, like the one that brought the great snowstorm of February 1933, develop entirely in polar air – how, it is not known.

The Bjerknes theory, however, has been a great help in forecasting the weather, especially in connection with the short-period forecasts which are the great need of the airman, and fronts, represented by pecked lines, have been regularly drawn since 1933 on the official weather maps issued by the Meteorological Office, and which may be seen displayed outside life-boat houses and such-like places. One of the greatest difficulties connected with forecasting at the present time is to foresee the birth of fresh depressions. Sometimes this is possible when it is known that two air-currents are drawing near each other, but in many cases it is not. The difficulty is increased by the fact that most depressions originate over the North Atlantic, where surface observations by ships are few, and upper-air observations by sounding balloons nil. Indeed, many scientists think it probable that much improvement in weather forecasting is not likely: they believe that the formation of depressions is as erratic and unpredictable as that of eddies in a stream, and that the 'trigger' that begins the growth of a depression may be something as accidental as the updraught from a burning ship or the melting of an iceberg.

Depressions certainly do behave in unexpected ways. For instance, the evening weather chart on August 7th,

1931, only showed a slight kink in the isobars over the region of the Irish Sea, but by the small hours of the following morning a vigorous secondary depression was in being over the Bristol Channel which brought unseasonably boisterous weather to many parts of the country. These secondary areas of low pressure often develop inside a large one; often, indeed, they become the deeper and more active of the two, and end by absorbing their parents.

Sometimes the isobars on the southern side of a depression (northern in the southern hemisphere) bulge out into the shape of a V, or sometimes into the more rounded form familiar to listeners to the broadcast weather forecasts as 'troughs of low pressure.' These V's can be connected with either warm or cold fronts; the latter type are often associated with line-squalls which accompany the passage of V's all over the world. Some of the most marked instances occur in Australia, where the storms called 'southerly bursters' are definitely connected with V's. In these storms the wind suddenly changes from north-east to south-east, the temperature drops suddenly by almost incredible amounts (30° or 40° F. is not at all unknown), and, like the line-squalls of this country, there is a long roll of cloud and frequently thunder and lightning. The same phenomena occur with the 'pamperos' of the Argentine, which are much feared by sailors at the mouth of the Rio de la Plata. Seamen have good cause to dislike these squalls, for, especially in the days of sail, they have caused the loss of many a good ship. One of the first line-squalls to be studied was that which caused one of the greatest disasters that have occurred to the Royal Navy in peacetime.

On March 24th, 1878, H.M.S. *Eurydice*, a full-rigged corvette, was running free before a westerly wind, with all sail set, off Ventnor, in the Isle of Wight, and her crew of over 300 men and boys were beginning to look forward to home after their cruise in the West Indies. At 3.45 she was struck by a line-squall that swept down at 38 miles an hour from the north-west. There was no time to shorten sail, so she went over on to her beam-ends, the water rushed in through the open ports, and she foundered there and then. Only five survivors were picked up.

To turn to other forms of isobars, it is often noticed that a period of bad weather is broken by beautifully fine spells. These spells, in which the weather is of the kind described as being 'too fine to last,' are due to the presence, between the members of the procession of depressions to which the stormy period is due, of wedges of high pressure. The weather in a wedge is at first very fine and pleasant, with blue skies and light breezes. Though calm and fog are apt to occur in the centre, the atmosphere on the outskirts is often peculiarly transparent, a state of affairs that has given rise to proverbs such as:

> The further the sight the nearer the rain,

and may have been the real reason for the shipmoster's pessimism in the 'Ballad of Sir Patrick Spens':

> I saw the auld moon late yester e'en
> Wi' the new moon in her arm,
> And if we gang to sea, master,
> I fear we shall come to harm.

For, though the earthshine on the moon has really nothing to do with the weather, being caused by the

lighting up of the dark portion of our satellite by sunlight reflected from the earth (which to an observer on the moon would be then nearly 'full'), it is naturally much more visible when the air is clear than when this is not the case.

Incidentally, there is another belief that the appearance of the 'old moon in the new moon's arms' is a sign of good weather, a saying that is probably associated with clear air at the rear of a depression, or in an anticyclone.

Another belief which is perhaps connected with the great transparency of the air in the front of a wedge is that held by the Manx fisherfolk that the optical phenomenon of the green flash (the appearance of which is much favoured by a clean atmosphere) is a sign of shipwreck. It is a fact that the passage of the crest of the wedge is sometimes marked by a sudden thunderstorm or shower which might be dangerous to small boats; also, in any case, the wedge is often quickly followed by a depression, with its frequently rough weather.

The principal high-pressure system, however, is the anticyclone, which received its name in the first instance from the fact that the winds blow round the isobars in the direction of the hands of a clock – that is, contrary to what they do in depressions, or cyclones, as they were called at the time when the name was given. In this part of the world anticyclones are usually large, more or less oval areas of high atmospheric pressure, the highest pressure being found in the centre. Unlike depressions, in which the isobars are often packed rather closely together, anticyclones generally have their isobars rather widely spaced, giving rise to feeble gradients and light winds. Often there is calm at the centre.

Anticyclones have a general reputation for fine weather, and to some extent this is true. In summer, and sometimes in winter, the weather is fine, with hot days and cool nights, for the absence of cloud allows free passage to the sun's rays by day, and to the heat radiated back into space by the earth at night. For this reason at night there is often heavy dew and mist in valleys, which disperses readily in the morning as soon as the sun's rays warm the air above its dewpoint. Many proverbs are based on this fact, such as one from the French province, just over the water, of the Pas de Calais:

> Mist in the valley,
> Goodman go on your journey.

Another rhyme says:

> The dews of the evening industriously shun:
> They're the tears of the sky for the loss of the sun.

The great contrast in temperature between day and night in this kind of weather may have been the reason why the moon has often been blamed for the alleged injury to the health of those who sleep in her beams. This belief is very old, occurring in Psalm cxxi.: 'The sun shall not smite thee by day, nor the moon by night,' and is said to be supported by the personal experience of travellers in the East. On such clear nights the moon is very bright, so it would not be unnatural for persons unacquainted with the phenomena of radiation to regard chills, really due to the fall in temperature and the heavy dews, as resulting from the effect of the moonlight, especially in view of the many superstitions that have gathered around our satellite.

In winter and the early part of the year frost is very

likely in anticyclones, and the possibility is always mentioned in weather forecasts. This information is very useful to gardeners and fruit-growers, who can take steps to protect their orchards, etc. One method, which at one time was very popular, is to build smudge fires, the smoke from which makes an artificial cloud over the ground, which, like a real cloud, helps to check radiation; but up-to-date horticulturists often meet the difficulty another way – by heating the air near the ground with oil-burners.

Winter anticyclones are often not very pleasant, for the fogs which develop during the night are not dissipated during the day, but last for long periods. The sky in winter anticyclones, too, is frequently overcast with a persistent and depressing mantle of cloud, conditions which doubtless have largely helped to give these islands their bad reputation among foreigners as lands of fog and mist, where, in the words of Alexandre Dumas, 'the sun resembles the moon.'

North and south of the trade-wind belts the earth is girdled by two more or less permanent and continuous belts of anticyclones, the general position of which is about 30° N. and 30° S., the northern belt being the 'horse latitudes,' described in a previous chapter. These are part of the general circulation of the atmosphere, and seem to mark regions of diverging air-currents descending from the upper levels of the atmosphere.

In winter-time, owing to the rapid cooling of the land and the air above it, which becomes in consequence heavy, anticyclones pile up over the continents, the most marked instance being Siberia. A more interesting case is that of Spain, for the winter anticyclone that develops over the peninsula is strong enough to fend off

the travelling depressions that traverse the Mediterranean at that time of year; so Spain not only has to endure the dry summer common to all countries in Southern Europe, but a dry winter as well, receiving most of its rain during the transition periods of spring and autumn.

It seems likely that anticyclones would develop over the vast snow- and ice-covered areas of Antarctica and of Greenland, but, owing to the lack of information from both these regions, there is much uncertainty as to the actual state of affairs, but it seems, so far as Greenland is concerned, the cold layer of air is rather shallow, and not capable of fending off some, at least, of the many depressions of those regions. But much research is needed; though many crossings of the Greenland ice-cap have been made by sledge, only two series of continuous observations on the ice-cap have been made – by Mr. A. Courtauld, of the British Arctic Air Route Expedition of 1930–1, and by members of the German expedition, led by Dr. A. Wegener, that at the same time were exploring the country further north. Many books have rendered the details of Mr. Courtauld's winter vigil familiar to the public, but it is perhaps not quite so well known that at the German station of Mid-Ice, Dr. J. Georgi spent a whole year with one or two colleagues in an ice-cave, and made most valuable observations, even during winter storms when 'in a few moments the face is covered by a hard crust of ice and snow; it is impossible to keep the eyes open, nearly impossible to walk the few yards to the meteorological screen. At such times during the period of darkness every meteorological observation involves a struggle for life, for if he

misses his goal by one yard the observer is lost beyond recovery' (Loewe in *Q.J.R. Meteor. Soc.*, 1936).

The causes of the winter, continental, and 'horse latitudes' anticyclones are fairly clear, but there is no generally accepted theory for the oval anticyclones that affect our weather. It is known, however, that they are of two kinds, those with warm centres and those with cold, and that their formation must involve the accumulation over the area occupied by the particular pressure system of vast quantities of air, the weight of which in tons must be reckoned by the hundred thousand million. The reverse process, of course, must take place during the formation of a depression, but how these millions of tons of air are moved is not yet known, beyond the fact that most of the movement must take place in the upper air.

There are two other minor pressure systems, the col and straight isobars. The first of these is the saddle-shaped area that is found between two depressions and two anticyclones. It is a region of calms and rather indefinite weather, with a tendency towards fog in winter and thunder in summer. Straight isobars is the name given to the atmospheric situation when the pressure distribution is such that the lines showing equal atmospheric pressure are not curved. It is an unstable condition, which is often followed by a depression in the same place the next day. For this reason many of the features of straight isobars, such as the 'sun drawing water' through chinks in the clouds, great clearness of the atmosphere under a cloudy sky (unlike the clearness in a wedge when the sky is cloudless), and also the unusual distinctness of distant sounds, are well-known signs of rain.

There is no room here to give a full account of how weather forecasts are prepared from the study of weather maps, which not only show the pressure systems existing at the time, but other details of the weather, such as wind, temperature, rainfall, etc. The forecaster's task is to decide not only how far and in what direction the pressure systems will move in the near future, but to estimate how they will change in themselves, and how the nature of the face of the country will affect the resulting weather. For instance, a mountainous district like Cumberland may experience quite different weather from that occurring in the flat country of Lincolnshire, and that is one reason why the British Isles are divided up into 20 forecast districts.

These local peculiarities of weather are sometimes very marked, especially in mountain districts or on the coast, a fact which accounts for the great weather wisdom, as far as local conditions are concerned, of fishermen, shepherds, and the like. When tramping or climbing in mountain or moorland districts, in addition to consulting the general weather forecast as broadcast or printed in the Press, it is very advisable to consult some knowledgeable local inhabitant. Disregard of such advice resulted in two friends of the writer having rather a disagreeable experience in the Alps. They set out on an Alpine ramble at a later hour in the morning than the time at which they had been advised to start, and, though they reached the summit safely, on their return they found that a thunderstorm had broken out below them. They had to remain literally marooned on the mountainside for some time till the storm had dispersed, and, after an uncomfortable descent in the failing light, reached their hotel safe, but so late that

great anxiety had been aroused as to their safety and a rescue-party organised.

On the other hand, local knowledge does not often give much clue to the general situation. Some years ago the men of an Irish fishing-village, presumably thinking that all would be well, set sail as usual one morning. But the officials of the Meteorological Office, from the information they had received by radio from ships on the Atlantic, knew that a depression was approaching and a warning was broadcast. The priest of the parish received the message, and at once went down to the shore, but the fishing-fleet had sailed. In the ensuing gale 40 of his flock were drowned. The other side of the picture is shown by recent reports that the reduced losses of the Breton fishing-fleet during the gales of 1936 are probably due to the radio broadcasts. Surely such instances reconcile even the most keen listener to those rather dramatic interludes when the strains of the concert or the patter of the variety show fade out and are replaced by a voice: 'The Meteorological Office issued the following gale warning at . . .'

The story behind these familiar words is a long one. The old Hindu sages discussed weather signs, and the clay tablets of Babylon and Assyria contain predictions of this sort: 'When it thunders on the day of the moon's disappearance, the crops will prosper and the market will be steady.' The Babylonians also worked out a scheme of predictions based on the occurrence of thunder in each of the 12 moons, a scheme which passed from Asia to the west and survived in Europe into the Middle Ages. Even now it is still believed by some that the phases of the moon influence the weather,

and that the position of our satellite when a crescent also has forecast value, as is expressed in the Scottish rhyme:

> The bonny moon is on her back;
> Mend your shoon and sort your thack.

But in Suffolk the contrary belief is held, for the moon 'on her back' is thought of as a sign of fair weather, as it is supposed, in this position, to retain the water which it is thought is in it.

These ideas must be a direct legacy from times when nothing was known about the actual causes of the phases of the moon, which it is scarcely necessary to say are due to its being a globe and changing its position relative to the sun. The position of the horns of the crescent also depends upon the changes in the position of the moon in regard to that of the sun, and goes through a regular cycle with the seasons.

The same idea of times and seasons is shown in the ltitude of proverbs that connect weather with par-ular days, mostly now, since the advent of Chris-nity, with saints' days and the various festivals of the Christian year, such as the idea, criticised as long ago as 1400, that the weather of the 12 days between Christmas and Twelfth Night foreshadows that of the 12 months of the coming year. Other proverbs of this kind are on a surer foundation; the proverbs about the three 'ice-saints,' SS. Mamertius, Pancras, and Gervais, whose anniversaries fall on May 11th, 12th, and 13th, are probably the popular recognition of the fact that during May bursts of cold air are apt to disturb the regular rise of temperature. In the same way, as has been pointed out by a well-known meteorologist, the really overworked and over-discussed rhymags amt St. Swithun may give

expression to the fact that there is a rise in the average rainfall of Western Europe at this time. Certainly nearly every country in that district has its own particular proverb attached to the most convenient local saint. In Belgium the day is either St. Godelieve (July 6th) or the Visitation of the Blessed Virgin Mary (July 2nd). This anniversary also occurs in the proverbs of Austria, Denmark, and the Lower Rhine, where it has such a watery reputation that it is called 'Mary Drip Day.' Another German day is that of the Seven Sleepers (June 27th), and it is a fact that in 1930 it rained on that day and for the traditional 40 days after!

Many weather proverbs, such as those quoted in the first part of the chapter, are really founded on observation. Others show much traditional wisdom, such as the Danish:

'The almanac maker makes the almanac, but God makes the weather.'

But nothing could be done until some knowledge was gained of the actual processes of the atmosphere. Soon after the invention of the barometer in 1643, Dr. Robert Hooke realised how observations of that instrument could be used for weather prediction, and not only drew up a scheme for observations, but designed a special instrument for use at sea. But the great difficulty in the way of such early attempts was the lack of means of speedy communication, and this was not supplied till the invention of the telegraph, by which time meteorological observers had received more tools for their work in the scale of wind force and the code of letters devised by Admiral Sir Francis Beaufort. These letters, which are usually the initial of the phenomenon – e.g. b for blue sky, r [illegible]in, s for snow – are still

used in the English-speaking world, though for international use a code of symbols has been prepared, and in this country is used along with the 'Beaufort' letters.

In a brilliant speech before the old Meteorological Society of London (a forerunner of the present Royal Meteorological Society), a young graduate of Christ Church, Oxford, named John Ruskin, had emphasised the importance of collective effort in the study of the weather. Some 20 years after, following the invention of the telegraph, Professor Henry in America and James Glaisher, F.R.S., of Greenwich Observatory, began the collection of weather observations. The British observations were published in the *Daily News*, and during the Exhibition of 1851 were embodied in maps which were sold to the public, but after the end of the Exhibition the venture came to an end. But soon afterwards the Crimean War broke out, and much hardship was caused to the British and their French allies by a great gale which not only destroyed a French warship, but sank vessels containing warm clothing for the troops and fodder for the horses. The great astronomer Le Verrier, one of the discoverers of the planet Neptune, investigated the gale, and was able to convince his Government of the value of telegraphy, and by 1860, with the support of the Prince Consort and the British Astronomer Royal, Sir G. B. Airy, was able to co-operate with the Meteorological Department of the Board of Trade which had been set up in 1854 under Admiral FitzRoy. This application marks the beginning of the daily weather reporting service in this country, and-the issue of the *Daily Weather Report* began on September 3rd, 1860. After FitzRoy's death in 1865, the issue of gale warnings and forecasts was suspended

for a time, but very soon the gale warnings were restarted owing to pressure from the Board of Trade, and in 1879 weather forecasts were begun once again.

During the succeeding years the Meteorological Office has undergone many vicissitudes, but, generally speaking, its history is a record of progress. More and more generous grants were made from the Treasury, the invention of radio enabled information for the first time in 1907 to be received from the hitherto inaccessible stretch of the Atlantic, and an elaborate international organisation had been built up.

About this time, too, the study of the weather in this country received great encouragement from a typically gracious but not very well-known action of his late Majesty, King George V. Though the Royal Meteorological Society had received the grant of that title in 1883, the personal patronage of the sovereign had not been given. But in 1904 King George, then Prince of Wales, became patron because he realised, from his own experience as a sailor, how important the study of meteorology was for the well-being of the nation and Empire, and he remained in that position till his lamented death in 1936, since when his example has been followed, first by Edward VIII, and then by our present beloved King George VI.

During the reconstruction that followed the upheaval of the war period, 1914–19, the Meteorological Office was placed under the Air Ministry. Though in some respects the war had given a great push to meteorology on its practical side, owing to the need for forecasts of weather not only for the newly created air services, but for military activities of all kinds, the elaborate machinery for the international exchange of information

about the weather had been entirely wrecked, and had to be set up again. Now, however, it is working as smoothly as any international body, and the forecasts published in the Press and broadcast by the B.B.C. represent the work of thousands of observers of all sorts and kinds scattered throughout the northern hemisphere.

At certain agreed hours these observers go out and note the weather, such as the kind and amount of cloud, rain or snow if any, the clearness of the air or 'visibility,' the wind, the temperature, the height of the barometer, and, what is most important, whether this is rising or falling. Having noted these, they prepare a telegram in a code which in Europe generally consists of five groups of five figures each. Many fully equipped stations send in reports four times a day, but there are a good many stations in this country and elsewhere where so many observations are not possible. Most stations, however, contrive to furnish reports from observations made at 7 a.m. Greenwich time.

'All sorts and conditions.' Few phrases could better describe those who, when it is 7 a.m. Greenwich time in England, are hastening towards their instruments. In Canada or Siberia a fur-clad observer may be tramping through the snow or fighting his way through a blizzard. On some luxury liner or one of H.M. ships the officer of the watch may be estimating the amount of cloud, wrapped up against an Atlantic gale, or in white tropical kit in the sunshine of the Mediterranean. Officers of the Air Force, or of civil machines, students at a famous school in the North of England, fair Norwegians, Swedes, and Dutchmen, dark French, Italian and other South Europeans – indeed, members of most

of the nations of the northern hemisphere – are observing the weather at this hour and reporting to their central offices.

Most Londoners are familiar with the great aerials above the fine building of the Air Ministry at the Aldwych end of Kingsway. From 7 a.m. onwards these aerials are busy receiving weather reports, first from home stations, then from ships at sea, and then from Europe. By international arrangement three high-power radio stations in Europe broadcast a representative selection of the weather reports made in their district, Moscow being responsible for sending on observations made in the widespread Soviet territories in Europe and Asia, Paris for Western Europe, and Berlin and Hamburg for Central Europe. Later on the great station at Rugby radiates a summary of the weather conditions in the eastern hemisphere for the benefit of America, and in return the United States sends out information regarding the weather in that part of the globe.

As soon as each message is received at Kingsway it is taken down by the operators on duty and sent, still in code, to the forecast room below, where it is decoded and the observations plotted on a map, and thus gradually a picture is built up of the weather conditions over the northern hemisphere. Similar maps are prepared from reports of the observations taken at the other standard hours – 1 a.m., 1 p.m. (or 13.00 hours) and 6 p.m. (or 18.00 hours). The maps and forecasts published in the Press are based on observations made at the last of these times, and the long interval between the time of observation and the time when the forecast reaches the public probably accounts

for many apparent failures, for in 12 or 14 hours many changes may happen – like the instance quoted earlier in the chapter when a vigorous secondary developed out of nothing between 6 p.m. on one evening and 1 a.m. the next morning. Fortunately, nowadays the latest weather information is given in the morning in the 10.30 broadcast.

The radio weather reports may be received and used by anyone knowing Morse and the special code, copies of which are obtainable, but unfortunately both Rugby and the Air Ministry station work on wavelengths outside the range of ordinary receiving sets. At establishments, however, like the Royal Naval College, Dartmouth, these messages are regularly received and used in the plotting of charts, and the case has been recorded of one student so skilful that he could put the symbols on the map straight from the Morse without indulging in the usual practice of writing down the code groups and constructing the chart after the message was over.

Weather forecasting in this country is particularly difficult owing to the fact that the British Isles are, speaking meteorologically, the cockpit of the northern hemisphere, where the weather influences from the depression over Iceland, the high pressure of the 'horse latitudes,' and the varying conditions over Europe struggle together, first one and then the other gaining the mastery. First the Icelandic depression wins the victory, and there follows a wet, mild, and stormy interlude, with a constant procession of depressions travelling across the country; then the winter anticyclone over Europe may gain the mastery for a space, and the warm south-westerly winds are replaced by the bitter north-easters. Or, in summer, the high pressure

of the 'horse latitudes' on its annual excursion north may extend far enough to cover the south of England, and, by keeping off the depressions, bring to these shores the heat and drought of the Riviera.

Other difficulties result from the fact that, in the words of a bygone meteorologist, one Blasius, 'a storm must be treated as an individual which is subject to development.' Even the speed of travel of an individual depression is not constant throughout its existence.

Then there is still a lack of information, particularly from the Atlantic, both as regards conditions on the surface and the upper air, and Western Europe gets most of its weather from that direction. Proposals have been made to establish floating observing stations in the ocean, and, though nothing has so far been done, perhaps the proposed air routes to America may lead to action. And, though there is a good network of surface observing stations in Europe, upper air observations are not so numerous as they could be.

Difficulties also arise from the nature of the air itself; as it partakes of the nature of a fluid, its motion is of the kind called unstable, unlike the motions of the planets, which are stable. We can tell what Mars will be doing 100 years hence; we scarcely venture to guess what the air over England will be doing 100 hours hence. It is owing to the nature of unstable motion that, though it is possible to say in the forecast that Derby Day, for example, may be showery, it is not possible to predict whether the great race itself will be nearly 'washed out,' as all but happened in 1911, when, just after the races were over, such a heavy shower fell that 2·44 inches were recorded at Epsom.

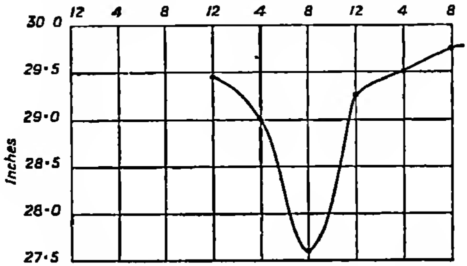
As far as the daily forecasts go, the results are quite

satisfactory, and, in addition to supplying the published and broadcast forecasts to the public, the office does a great deal of work in answering the inquiries of persons who want a private telegram. These range from Atlantic flyers to farmers, and even include a society lady who wanted to know what she should wear at Ascot the following day.

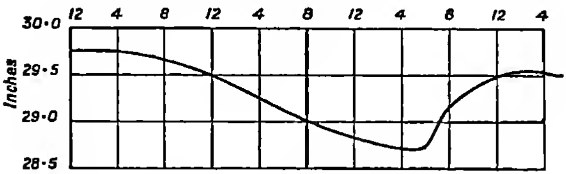
Recently much prominence has been given to the recurrent spells of warm and cold weather associated with the name of Alexander Buchan, a prominence not unmixed with misunderstanding. For, as pointed out in a recent book by Mr. E. L. Hawke, F.R.Met.Soc., though there is a tendency for these nine warm and cold spells to recur about certain dates, it is a tendency, and no more. Nor did Buchan claim anything else.

Every civilised country nowadays has its meteorological bureau, though the nature of the work varies somewhat according to the differing circumstances of each country. The United States Weather Bureau, for example, does a great deal of work in the prediction of floods in the Mississippi and other river valleys, and but for the work of Weather Bureau officials the loss of lives and property in the great floods of 1937 would have been much greater than it actually was. The same can be said of the hurricanes that from time to time visit the shores of the southern United States, for the warnings issued enable numbers of people to escape from the low-lying shores of Florida and Texas before these are swamped by the huge waves raised by the storm. Prediction of these violent storms is also a great part of the work of observatories in the Far East. No visitor to Hong Kong can fail to notice the typhoon warning boards on which warnings from the

Royal Observatory are posted as and when required. Before the Observatory was established at Hong Kong, the merchants of the city were obtaining reports from that at Manila, which was founded by Father Faura, S.J., in 1865. Shipping of all nations has owed much to the Spanish Fathers at Manila and their French



Typical barograph trace – hurricane (after Miami 1926)
Very steep gradient



Typical barograph trace – depression (fictitious)

Fig. 16

brethren at Zi-Ka-Wei, near Shanghai, for their intensive study of these highly dangerous storms, a study which earned one of their number, the late Father Louis Froc, the affectionate nickname of 'le père des cyclones.'

Tropical cyclones, the hurricanes of the West Indies, the typhoons (Chinese *tai-fun*, great wind) of the China

Seas, the *baguios* of the Philippines, the cyclones of the Indian Ocean, and the hurricanes of the South Seas, are low-pressure systems which somewhat resemble the depressions of these latitudes, but are much smaller and deeper (Fig. 16). They also differ from the ordinary depression in being circular instead of oval in shape, and having in their centre a small area of calm called the 'eye of the storm.' So still, indeed, is the air that the flame of a match may burn with perfect steadiness, yet, only a few miles away, the wind may be blowing 'twelve on the Beaufort Scale' – that is, more than 75 miles an hour. More often than not, indeed, the wind speed goes into three figures, and often passes beyond the capacity of the Dines anemometer, which, as at present constructed, cannot register beyond $122\frac{1}{2}$ m.p.h. Since so many observatories in cyclone areas use this instrument, experts are considering the possibility of modifying the float in some way so as to render it capable of recording high velocities.

There are many thrilling accounts extant of these storms. Fifty years ago the country was stirred by the tale of the escape of H.M.S. *Calliope* from the harbour at Samoa in 1889. Several warships were trapped in the anchorage, with results that can be imagined. At last Captain Kane decided to take his ship out to sea, for to stay behind meant collision or shipwreck. So the *Calliope* steamed out into the storm, while the crew of the U.S.S. *Trenton*, forgetting their own peril, cheered her as she passed.

A more recent description of such a storm in the same part of the world was given in a recent number of the *Quarterly Journal of the Royal Meteorological Society*.

The captain of the auxiliary ketch *Endeavour* described how his ship ran into a hurricane near the Fiji Islands, and how he had to heave to, as a huge sea had smashed the door of the engine-room and flooded the engine. Four hours later the centre passed over the ship and there was a dead calm, but soon a breeze sprang up from the opposite quarter to that from which it had been blowing, and soon 'I experienced considerable difficulty in breathing. The wind lifted continuous spray over the ship, which struck my face, arms, and legs with a force that I can only describe as if a person of average strength was pelting me with handfuls of small pebbles. Seas were breaking over the bulwarks continually. Suddenly the lifeboat was lifted in the air from the starboard side of the deck and dashed overboard. I cannot swear to it, but as I saw no sea break over at the time I concluded it was the wind that lifted it. The bowsprit, which I noticed jerking violently, snapped off close to the heel, and the forestay snapped. . . .'

Ships, however, nowadays have a much better time than towns, for with luck they are able often to avoid storms entirely, or at least escape crossing the centre. The old practice in the days of sail was to run before the wind, a custom which resulted in the *Charles Heddle* being carried five times round the storm centre. Then came Reid, who, in 1846, gave rules for handling a ship so as to avoid the 'dangerous semicircle.' In modern times the wireless broadcasts from various observatories often enable a ship to dodge the storm altogether.

The inhabitants of towns are not so fortunate, and, even now, great loss of life and damage to property

occurs from time to time. Thus, in Santo Domingo, in the West Indies, 2,000 people lost their lives in the hurricane of 1930. As for the city, an eye-witness declared that it was 'practically destroyed; the storm did in four hours what it used to take a 15-day bombardment in France to do. . . . Whole streets everywhere are blown down, the houses have collapsed or fallen bodily into the streets; there is probably not a single whole house in the city.'

The damage done by hurricanes to crops, etc., accounts in some measure for the chronic poverty of many of the smaller West Indian colonies. On the other hand, it must be remembered that many tropical disturbances occur which are so mild that they do no damage, and are beneficial because of the rains they bring. Indeed, the late Dr. O. L. Fassig has estimated that, at Porto Rico, only one bad storm would occur in the next generation as against 12 beneficial ones and six of an intermediate kind.

The energy in one of these tropical storms is enormous. It has been estimated that in one day a cyclone expends enough power to work all the machinery in the world for three or four years. Even an ordinary depression may be energetic to an unbelievable extent. It has been calculated that during the gale of January 12th, 1930, enough power was crossing the square mile in the English Channel in one hour that if it had been converted to electrical units and paid for at the popular rate of ½*d.* per unit the bill would amount to £750,000,000 !

It is the contemplation of such displays of energy that brings the realisation of how futile are the ideas of some who imagine that one day man will control the

weather. It may be quite possible that the future may bring improved means of forecasting the weather, even that of the coming year, and that plans for clearing aerodomes of fog by heating or electrical means may bear fruit, but it does not seem within human power to guide the whirlwind and control the storm. Perhaps it is as well that this should be so, for it is not difficult to imagine the burden that would be laid upon those responsible for choosing the weather, the burden of adjusting the conflicting claims of different classes of the community, and even of different nations. The old Tartar proverb contains much wisdom:

'The peasant prays for rain, the traveller longs for sunshine, but God gives each what is best.'

[Since this chapter was written the observations made during 1937 by the Soviet party at their floating north polar station during 1937 have become available; these furnish additional information as to polar weather. Full details are to be found in the recent book *On the Top of the World* (Gollancz 1938), but generally speaking the weather was damp (from this it seems the statement about polar climates on p. 185 may need modification), overcast, and foggy. Temperatures seem to have been in excess of those obtained forty years ago by Nansen in much lower latitudes; this may be connected with the general amelioration of climate in these regions (p. 192).

It is also anticipated that much information as to weather in the Antarctic, will be gained from observations made by the British Graham Land Expedition between 1934 and 1937; it is likely an account of these will appear shortly in the *Geographical Journal*.]

CHAPTER VIII

Climate

It's North you may run to the rime-ringed sun
  Or South to the blind Horn's hate;
Or East all the way into Mississippi Bay,
  Or West to the Golden Gate.

L'Envoi, Rudyard Kipling

Very early in history it must have been noticed that the general weather conditions between one part of the world and the other differed greatly. Thus, in the xiv century b.c. the contrast between the rainless climate of upper Egypt and that of Palestine and Syria, with its winter rains, was expressed in verse by the 'heretic,' Pharaoh Akhenaton, who, in his well-known hymn to the sun, so finely translated by the late Professor J. H. Breasted, describes first how the Nile has been created for the benefit of Egypt, and then:

All the distant countries,
Thou makest also their life,
Thou hast set a Nile in the sky
Whence it falleth for them,
It maketh waves upon the mountains
Like the great green sea,
Watering their fields in their towns.

Similarly, when Herodotus visited Egypt some eight centuries later, some of the priests with whom he talked thought Egypt, with her regular Nile flood, a much more favoured country than Greece which had to depend upon capricious winter rains.

The conventional division of the world is into five climatic zones, two polar, from the poles to the Arctic and Antarctic circles respectively, the temperate zones between the two circles and the tropics, and the torrid zone between the tropics. Actually, however, this division breaks down entirely, for, though it would work in a world which was either all land or all sea, it fails in a world containing both. Also, it does not take into account the modifications produced by the different elevation of the land, for the temperature falls at a rate of 3° F. for every 1,000 feet. Owing to its elevation, Bloemfontein has the same average temperature as Cape Agulhas, though it is over 300 miles nearer the equator.

The whole question of climate is such a large and complicated one that only the briefest outline can be attempted here. Each type of climate mentioned below has many modifications that have been classified with typically Teutonic minuteness by that veteran of climatology, Dr. W. Koppen, now (1938) in his 92nd year, and who, besides many of the more usual scientific distinctions, has had a street named after him in Hamburg, where for many years he presided over the Deutsche Seewarte, that branch of the German meteorological service that looks after the interests of shipping.

Generally speaking, however, despite the modifications mentioned above, there are certain definite types of climate. Beginning from the equator, the characteristics of a tropical climate may be summed up in one good old English word – muggy; for it is hot, wet, and cloudy.

There is little distinction between summer and winter

in the belt of tropical climates, the seasons being marked more by the distribution of the rainfall than by anything else. On the equator the mercury usually hovers about 80° F. throughout the year. At an inland station like Brazzaville, in the Belgian Congo, the difference between January and July may be about 8° F.; at the sea coast the moderating influence of the water greatly reduces the difference. At Batavia, the

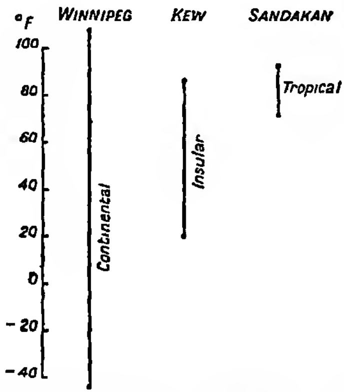


Fig. 17. Extreme annual range of temperature (1936 figures) in different types of climate

average annual range is only 1·8° F., and on a small island like Ocean Island it almost vanishes, being only half a degree ! Indeed, as the difference between day and night is often greater than that between summer and winter, night is frequently called the winter of the tropics. But even night does not always bring much relief, for the temperature only drops a few degrees. Fig. 17 shows the extreme annual range (1936) at Sandakan.

It is this monotony in the temperature that helps to

make tropical climates so enervating for white men. Also there is the great humidity of the air; the damp heat in places like the coast of Portuguese East Africa unsticks the bindings of books through the action on the paste. The great amount of water in the air hinders perspiration and the natural cooling of the body, and so conduces to heat stroke, to which many of the deaths in American heat-waves are due, for the heat-waves of the United States are very different from the spells of hot weather that are dignified by that title in the daily Press of this country. American heat-waves are due to the invasion of that country by streams of hot, damp air from the Gulf of Mexico that bring tropical conditions to New York. The part played by damp heat in bringing about this very dangerous condition was very clearly shown by medical reports on the cases occurring among Italian soldiers and workmen in East Africa during the Abyssinian war, for, while cases happened even in the shade in the damp and hot low-lying districts round the Red Sea, in the same latitude in the highlands of Eritrea, where the temperature was less owing to the increased height, the men were free from this form of illness.

White men newly arrived in the tropics soon find that they have to slacken their pace, discovering that a quick walk of even a couple of hundred yards or so causes them to perspire freely, a rather uncomfortable experience, for, owing to the humidity of the atmosphere, the sweat takes some time to evaporate, during which reading or writing is somewhat awkward, for the perspiration may fall on the book or paper. Games are helpful, and most residents in the tropics, if they take reasonable care, enjoy fairly good health, but

sooner or later the climate tells on the health of the European, who tires easily and becomes less keen mentally, becoming forgetful and finding it difficult to concentrate, a condition known by such names as 'Malayan head,' 'Gold Coast head,' 'Burma head,' and so on. A return home for some time soon cures the trouble, and the white man comes back feeling fit again till once more the climate 'gets at him.'

The nature of tropical climates and their effect on white men has some important political results so far as the British Empire is concerned. The great ambition of many loyal Australians to see their country entirely 'white' has one great obstacle in front of it – the tropical character of the northern territories of the Commonwealth – and it has been found that the type of immigrant who acclimatises the fastest comes from Southern Europe.

On the other hand, those parts of Africa like the Gold Coast, where the climate forbids the presence of permanent settlers, and the only white men are officials, missionaries, etc., are the parts where the relations between the white and black races are the most friendly.

The rainfall in the tropics is heavy and variously distributed throughout the year. On the equator rain may fall in any month. The general average for the equatorial regions is 75 inches a year, rising in places such as Sierra Leone to 160. It is this rainfall that nourishes the dense forests of the Amazon and the Congo, and anyone wishing to have a good idea of the conditions in these jungles can gain it by going into an orchid house, in which the atmosphere has to be maintained artificially at the damp heat to which the plants are accustomed in their homes.

Passing further from the equator, a definite wet and dry season develops, and the quantity of the rainfall diminishes. North of the equator in Africa there is almost a continuous transition between the equatorial regions of nearly continuous rain and the desert.

The typical tropical climate is naturally much modified by various circumstances. On high ground, such as the inland tablelands of Central Africa, the climate is cool enough for white men to settle, and, even on the equator, Mount Kenya (17,040 feet) is high enough to have a small but beautiful cap of perpetual snow.

Beyond the zones of tropical climates come the trade-wind belts and the high pressures beyond. These regions are, at sea-level, districts of fair weather, steady or light winds, and occasional light rains, except where the trades blow against mountains, as is the case in Hawaii and Central America where heavy rain falls. Over the land, however, these belts include the great deserts of the world, which coincide closely with the centres of the high-pressure belts. At sea, in the corresponding positions, there are regions of high saltness and heavy evaporation. Inland there are great extremes of temperature, the mercury mounting much higher than it ever does in the tropics, but, as this heat is accompanied with dryness, it is much more bearable owing to the freedom with which perspiration takes place. Indeed, the loss to the body not only of fluid, but of salts dissolved therein, is so great, that the writer has been informed that employees of a well-known oil company in the Near East drink salted water, for it has been found that drinking plain water may bring on cramps owing to the loss of minerals from the tissues.

The desert type of climate has had important influences on the course of civilisation. As early as 4000 B.C. the Egyptians knew that burial in the dry, hot sand preserved human bodies, and probably began to think that such preservation was necessary for the future welfare of the deceased. From that it was only a step to artificial preservation, which gave birth in time to the elaborate technique of mummification and all the associated arts and crafts that were so characteristic of Ancient Egypt. Indeed, it is owing to the extraordinarily dry climate of Upper Egypt that we know so much of the everyday life in the days of the Pharaohs, for all kinds of knick-knacks are preserved that in damper lands would have rotted away long ago.

Again, is it only a coincidence that the desert regions of the old world, the hot dry climate of which has a stimulating effect on the nerves, should be the origin and the chief stronghold of that most fiery of creeds, Islam? No doubt, too, the precarious conditions of life in the desert would conduce men's minds towards a faith that stressed the overwhelming power of God and the impotence of man.

In the southern hemisphere in the Union of South Africa similar conditions prevail in the interior of the country, though temperatures are not so extreme as in the Sahara, for the peninsula is not only surrounded by sea on three sides, but has a general elevation of 4,000 feet. The same conditions of hot days and cold nights apply; the temperature may fall so low during the night on the high veld that men going to sleep in the open air have awakened to find their moustaches stiff with the frozen moisture of their breath. The west coasts of the Union are particularly arid, through

the influence of the cold Benguela current, in the same way that the Peru Coastal Current brings drought to the western shores of South America. The behaviour of this current is particularly interesting, for during the summer of the southern hemisphere, when the north-east trades cross the equator, it is replaced by the warm waters of the Equatorial Counter Current which the winds drive before them, and this warm current (called the Niño, or Child, by the fishermen, because it generally appears soon after Christmas) entirely reverses the climatic conditions, often bringing heavy rain to a district that is usually desolate and barren. Despite this, however, the Niño is not welcome, for often the influx of warm water kills the fish and other marine life to such an extent that the military have sometimes, as in 1925, to be called out to bury the decaying organisms that litter miles of beach. Large quantities of sulphuretted hydrogen are also set free in such amounts as to darken the paintwork of ships, hence the sailors' name of 'Callao painter.' More serious, perhaps, is the loss of food to the guano birds, which either die or migrate southwards, sometimes leaving their young to die in the nests; the loss to the guano industry may run into thousands of pounds.

The transition region between the sub-tropical high-pressure belts and the temperate zone produces a type of climate called after the region in which it is best developed – Mediterranean. Other districts are California and North Chili. The Mediterranean area is especially favoured, for the mountains to the north protect it from the cold winds, and the warmth of the sea ensures that usually even the coldest month has a temperature well above freezing-point. There are

many varieties of climate in the Mediterranean area, but the chief characteristics are the mild temperatures except on high ground, and the winter rains (Fig. 18).

The varieties of climate in the temperate zones are so great, especially in the northern hemisphere, that

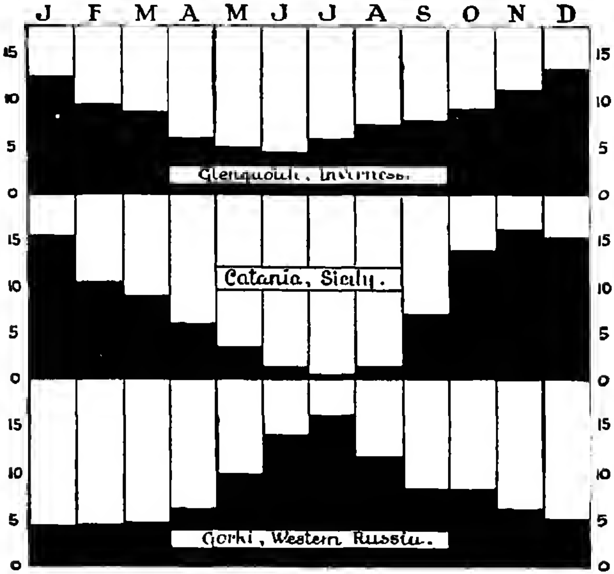


Fig. 18. Types of rainfall in different climates: Temperate (Mountain); Mediterranean; and Continental. (Glasspoole, *Q.J.R. Meteor. Soc.*, 1929)

the subject is very difficult to treat briefly. Generally speaking, the western shores of continents have mild winters and cool summers, and much rain and cloud. This is particularly marked in the case of North-western Europe in general, and the British Isles in particular, for the high temperatures of the North

Atlantic mean that not only are the prevailing westerly winds mild, but that they drive before them warm water. On the western coasts of North America and Europe the annual variation of temperature is often below 25° F., which is no greater than that in some part of the tropics, but the climate lacks the monotony of those regions owing to the frequent irregular changes due to the passing of depressions. The temperate zones, therefore, favour the production of the highest type of civilised man, for conditions are such that forethought has always been necessary for the provision of food, clothing, housing, and fuel – a very different state of affairs to conditions in the tropics, where little is really required in the nature of dress or shelter, and food plants almost grow of themselves. Some parts of the western coasts, however, are almost too wet, and such an authority as Professor R. A. S. Macalister has expressed himself in a very pessimistic manner as to the depressing effect of the damp climate of Ireland upon her inhabitants.

Further inland, climates become more and more extreme. A district near the sea has an equable temperature owing to the fact that water has a high specific heat, and therefore warms up slowly and cools down slowly; land, on the contrary, heats up quickly and cools quickly. During 1936 the extreme range of temperature at Kew Observatory was between 85° F. and 22° F. – 63 degrees – while Winnipeg had temperatures of 108° F. and minus 43° F. (75 degrees of frost) – a range of 151 degrees ! (Fig. 17). The heat of the Canadian summer is a great surprise to many people, and in the western districts warm conditions extend as far north as Aklavik, where trees grow to a

height of 40 feet. Some of the other features of Canadian summer weather are less pleasant. Owing to the Rockies intercepting the moist winds from the Pacific, there is a great tendency to drought in the Prairie Provinces, and there are other disadvantages best described in the reply of a settler to a well-known missionary bishop who had made a remark that the weather was grand. 'Yes,' was the answer, 'the Arctic would be ideal for a summer resort if it were not for those something, something mosquitoes.'

On the eastern side of Hudson Bay, that brings the cold water of the Arctic Ocean right into the heart of Canada, so cold are the conditions that, in an area five times the size of England, there is not a single tree, only creeping willow.

The most extreme climatic conditions, however, occur in the midst of the great land mass of Eurasia. The lowest recorded temperature of minus 93·6° F. was measured at Verkhoiansk, in Siberia, on January 3rd, 1885, and yet in the summer the thermometer soars into the eighties. As is the case with the low temperatures in Canada, calm generally prevails, so that the cold is quite bearable.

The eastern coasts of continents in the northern hemisphere share in the extreme climate of the interiors. This is particularly the case with North America, where it is accentuated by the cold Labrador current. The harbour of Quebec is closed by ice for five months in the year, while that of Glasgow, on the other side of the Atlantic, remains open all the year round, though it is more than nine degrees of latitude further north than the Canadian port.

The North American continent is particularly liable

to extreme climatic conditions, since, as the mountain ranges run north and south, there is nothing to prevent the cold air from the Arctic coming, as it often does, as far south as Texas. In Eurasia, on the contrary, the mountain ranges run east and west, and so the Mediterranean countries and India are guarded from invasions of the cold from the centre of the continent.

In the south temperate zone conditions are much more uniform owing to the large amount of ocean, the temperatures are equable, the winds steadier and stronger, and the weather much more changeable and stormier. New Zealand, which is on the boundary between the south temperate zone and the southern belt of high pressures, has one of the most ideal climates in the world; further south, however, conditions are rather dull and cheerless.

As regards the polar climates, there are great differences between the Arctic and Antarctic. There is no uniformity in the Arctic; the distribution of temperature is very complicated, especially during the short summer. Greenland has comparatively mild summers, and the reason why the inland ice is able to maintain itself is probably because it forms its own climate above it; also the snow reflects back a large percentage of the solar heat. For these reasons the Greenland ice, which no doubt was first formed during the last Ice Age, has endured. It is likely that if it once disappeared it would not be able to form again as things are now.

The Antarctic has a peculiar climate of its own, which has been appropriately named glacial. At sea-level, on the edge of the ice, even in summer the temperature remains below freezing-point owing to the cold

brought by the strong winds that are always blowing off the inland ice. The cold surface-water drifts north-east till it encounters the lighter and warmer water of the more temperate regions, when, being heavier, it sinks below. This convergence, as it is called, is very marked, and to one on board ship the crossing of the line is like passing from winter to spring. The difference in the nature of the two kinds of water is very clearly shown, too, by the different climates of Tierra del Fuego and South Georgia, which are in the same latitude and only 1,000 miles apart. The one, which is bathed by the warm waters of the temperate zone, is so thickly clad with trees that Darwin compared the richness of the district to that of a tropical forest. On the other hand, as all readers of Sir Ernest Shackleton's great book, *South*, will remember, South Georgia, surrounded by the cold polar waters, is a grim land of rocks and ice. Polar climates are dry because the cold air can hold little moisture.

There is yet another very important type of climate which is chiefly found in south-eastern Asia and which is governed by the changes of pressure in the interior of the continent. These give rise to the seasonal winds called the monsoons, which have been described in a previous chapter; they cause rainy summers and dry winters. It is in the monsoon regions that some of the most successful work has been done in long-distance weather forecasts, through a method developed by a former director of the Indian Meteorological Service, Sir Gilbert Walker. Sir Gilbert has been able to prove that the climatic conditions like temperature, rainfall at a given place at any time may be related to the conditions at other places at some previous time, and,

working on these lines, fairly successful forecasts have been made of the probable rainfall of the next monsoon in India.

Europe presents an interesting example of a monsoon climate that fails to come off. The Spanish peninsula is large enough for monsoon conditions to arise, and in winter is occupied by an area of high pressure with outflowing winds. But the corresponding low-pressure system which should develop in summer and bring rain-bearing winds to the country never materialises, owing to the northward advance of the high pressures of the 'horse latitudes,' hence the great aridity which has always been one of the great handicaps under which Spain has laboured, and such disagreeable climates as that of Burgos, bluntly described in the proverb as *nueve meses de invierno y tres de infierno* – nine months' winter and three months' hell!

But climates do not only vary in different parts of the same country; they differ greatly in different parts of the same town. Many interesting investigations in this direction have been made in Austria under the leadership of the late Professor W. Schmidt. Stations equipped with self-recording instruments were established in the Austrian Alps round Lunz, and a most extraordinary variety of local climates were discovered. For instance, at one station several sub-tropical plants grow freely, while at another, only separated from the first by a distance corresponding roughly to that between Kensington Palace and the Natural History Museum, grow grasses of the kind found in Siberia. This particular station is at the bottom of a hollow, with a bottom wide enough to allow of free radiation. In anticyclonic weather cold air flows down into this

hollow, making a kind of pond; this happens every clear night, winter and summer.

Another method developed by Professor Schmidt is the fitting up of motor-cars with specially mounted recording thermometers, so that records of the varying temperatures upon a given route, whether in the city or in the country, can be taken. It seems likely that much interesting information about the climates of a town could be obtained if a team of observers, belonging to, say, a natural history society, took simultaneous observations at agreed times with properly fixed thermometers at different places in the same town regularly. The results of observations made by a dozen or so people scattered over a town like Bath, for instance, would be rather interesting. Observations in the more remote districts of these islands, such as the Border country or the Derbyshire moors, might yield some surprising results. Interesting comparisons, too, might be made between town and country. It seems that large cities, owing to the great number of heated buildings, tend to develop a climate of their own. London has a snowfall much below the average for the district, and the effect is even more plainly marked in the case of Berlin, which turns a definite amount of the snow that falls in the neighbouring countryside into sleet, and the sleet into rain. It has also been suspected that the volume of heated gases rising from the mill chimneys of a certain manufacturing town in Lancashire is sufficient to give uplift to the atmosphere great enough to provoke an increased rain, the result being that Sunday, when the factories are not working, is the driest day of the week.

Climate not only varies from place to place but from

time to time. The recognition of this fact is at least three centuries old, for in the essay entitled *On Vicissitudes of Things* Francis Bacon wrote in 1625:

'There is a toy, which I have heard and I would not have it given over, but waited upon a little. They say it is observed in the Low Countries (I know not in what part) that every five and thirty years the same kind and suit of years and weathers comes about again, as great frosts, great wet, great droughts, warm winters, summers with little heat and the like, and they call it the prime; it is a thing I do the rather mention, because computing backwards I have found some concurrence.'

Two and a half centuries later this weather cycle was studied with great care by Dr. Brückner of the University of Bern and has received his name; but modern research seems to show that it is not, after all, a very important factor in the weather of Europe.

Another favourite cycle has been the sunspot cycle of about 11 years. The first to think there might be some connection between these outbursts on the sun and the temperature was the Italian Jesuit, Riccioli, in 1651, a connection which, it is reported, was confirmed by Dr. W. Koppen for the tropics in 1873. For the 25 years between 1896 and 1921 there was a most remarkable accord between the levels of certain lakes in Central Africa and the number of sunspots, but after 1921 the agreement between the two seems to have failed.

Indeed, many leading scientists think that there is not much reality in the cycles that have been put forward from time to time by various investigators. Usually they are either rather indefinite, or, if they are clearly stated, they break down under test, being, if

real, the result of some temporary state of affairs. For instance, during the 15 years 1868–82, every fifth year was regularly wetter than the others, but after 1882 the series broke down, and in 1889 another sequence began in which every third year was unusually wet. This particular sequence lasted till 1909, then it was replaced by a series in which every alternate year was wet, which lasted till 1922.

In addition to the small variations in climate that are continually going on all over the world, the study of the records of past conditions, preserved in the rocks, show that during the time the world has lasted many greater changes have taken place. To-day the Union of South Africa and Australia are semi-tropical countries, but geological surveys have proved beyond doubt that, millions of years ago, about the time the coal measures were being deposited in what is now England, the land in the two Dominions in question was under ice. In South Africa, deposits from the ancient glaciers cover thousands of square miles, and, in places such as the junction of the Vaal and Orange Rivers, are associated with that sure sign of the action of ice, the so-called *roches moutonnées* – that is rounded and polished boulders which have a fancied resemblance to sheep lying down. Similar deposits have been found in Australia and in other parts of the southern hemisphere. Why there should have been such an enormous accumulation in lands which, at present at any rate, are so near the equator, is a problem that has baffled geologists and meteorologists alike, and the only adequate theory is the very daring one put forward by the late Dr. A. Wegener that in the course of geological time there has actually been bodily

movement of the continents in relation to the poles and the zones of climate. Wegener's views, however, do not meet with universal acceptance, and there are certain facts which seem to militate against them, and, unhappily, their brilliant originator is no longer here to discuss them, for he died of cold and exposure on the Greenland ice-cap, at the age of 50, in 1930.

But the Ice Age which has really aroused the greatest interest (until quite recently it was thought to be the only one) is the one in the concluding stages of which we are probably still living. At a period the actual dating of which is still rather controversial, but was probably within the period of the occupancy of Europe by man, cold conditions set in which resulted in the formation of great ice-sheets that have been estimated to have covered, in the northern hemisphere alone, a area of 8,000,000 square miles, and which have marked the face of the land, including these islands, to this day. For instance, that deep cut in the South Downs near Brighton, known to thousands of holiday makers as the Devil's Dyke, is thought to have been cut by melt-water from the snow-cap that used to exist on the Downs, for, though the ice-sheet did not extend further south than just north of London, Arctic conditions must have existed close to its border. The famous cedars of Lebanon grow on materials that ultimately are derived from the moraines left behind by the glaciers that covered the mountains during the Ice Age.

. Of the making of theories to explain this cold period there is literally no end. The difficulties of an explanation are increased by the fact that the cold was not continuous, but interrupted by warm 'inter-glacial' periods. The theories can be grouped under three

main headings, geographical, solar, and astronomical.

The geographical theories attribute the onset of the cold to various changes in the distribution of land and sea, or to the rising of mountain chains, such as has taken place at various periods of the earth's history.

The solar type of theory regards the sun as a variable star, and attributes changes in climate to the variations in radiation received by the earth, owing to the changes in the activity of the sun. That something of this sort does occur in the sun is shown by the rather irregular 11-year period of sunspots, but as yet there is no proof of any variation over long periods of time.

As regards the astronomical theories, these account for Ice Ages by assuming changes in the orbit of the earth. At the present time this is nearly round, but, owing to various causes as time goes on, it may become more oval, or, to use the proper term, eccentric. As the earth moves fastest when nearest the sun, the hemisphere which has summer when this takes place has a short, hot season followed by a correspondingly long winter, and it has been thought that, under conditions of great eccentricity of the orbit, this long winter might lead to glacial conditions.

Another rather interesting theory is that which connects Ice Ages with volcanic eruptions. Observations have shown that, after great eruptions, such vast quantities of dust are thrown into the air that the solar radiation is much impeded. For instance, when the volcano, Katmai, erupted in Alaska on June 6th, 1912, ash fell to a depth of nearly half a yard at Kodiak Island, 130 miles away, and a fortnight later a marked diminution was noticed in the solar radiation as measured at stations in California and Algeria. This

diminution lasted for some time, and in August of that year reached as much as 23 per cent. Therefore, it is argued that if there were a series of powerful volcanic eruptions over a period of time, the temperature might be reduced enough to begin an Ice Age.

However, surer ground is reached when, instead of speculating upon the cause of the last Ice Age, an attempt is made to find out the approximate date of its conclusion. The melt-water from the edges of glaciers and ice-sheets is very turbid, being laden with sediment, and studies of the deposits of mud left behind in Sweden from the Ice Age show that the last ice-sheet began its retreat about 20,000 years ago, which retreat continued, with occasional halts, to the final break-up about 6500 B.C., which Scandinavian geologists regard as the end of the Ice Age.

Since the close of the Ice Age there have been many alternations of climate. For instance, between 2500 and 2000 B.C. the climate throughout Europe was unusually warm and dry, but between 800 and 400 B.C. it was very cold and wet. Again, at the time when the Icelanders colonised Greenland in the tenth century of our era the conditions in that country were much more favourable than they are to-day, Baffin Bay being almost free from ice. After the XII century, however, the climate grew worse and worse, and now ground that up to 1400 thawed to a considerable depth every summer became permanently frozen.

But the whirligig of time brings its revenges, and to-day we may be witnessing a return to more genial conditions such as existed 1,000 years ago. Since the beginning of the century there has been a steady increase in the winter temperature in Europe and its

neighbourhood, and in no place is the change more marked than in western Greenland. The immediate cause of this rise in temperature seems to be the dominance in the areas in question of mild south-westerly winds, but these are but the result of certain changes in the distribution of pressure over the Atlantic Ocean, though what gives rise to these alterations in pressure is still a matter for conjecture. As that great student of climatic changes, the late Dr. Brückner, said many years ago, 'We see the wheels turn and the hands move in predetermined rhythm, but the driving-force of the spring is hidden from us.'

But though the ultimate cause of the changes of climate, great or small, may be hidden, its results are very apparent, and no more so than in the effect of such changes upon plant and animal life. One of the most fruitful branches of amateur scientific work in this country has been the Phenological Survey, which since 1891 has been carried out annually by a team of over 500 voluntary observers under the auspices of a Committee of the Royal Meteorological Society (at present; in the future some modifications are likely in the control of the work), who, by noting the times of such events as the first flowering of various representative plants, times which vary widely from year to year, aim at working out some connection between climatic conditions on the one hand, and various stages of farm and garden cultivation on the other.

In this connection it is interesting to record that, at one place in Norfolk, records of this kind have been kept, with a few interruptions only, by members of the same family since 1736.

Observations are also taken on the time of arrival of

migrant birds and the appearance and behaviour of various insects.

This sort of work has a considerable practical value. Twenty years ago the Hessian fly was working great havoc among the winter wheat in the United States, but, by using 40,000 records, Professor A. D. Hopkins was able to prove that by sowing the wheat in the 10 days' interval between the time that the late-flowering golden rod first bloomed and faded, not only would the crop escape the attentions of the fly, the adults of which are all dead by the time that the golden rod is in flower, but the sowing would be soon enough in the season to escape the equally unwelcome results of the early spring frosts. In the same way, in this country, observations of the purple flowering cherry-plum have given the best date for the sowing of spring oats, so as to avoid not only the danger of damage by frost in March, but also the risk of the oats being too immature to resist the attacks of the fruit fly in May.

Nor are the effects of climate and its changes confined to the plant world. The founder of medicine as a science, Hippocrates, wrote a treatise on the effects of climate on man, and in the 2,400 years that have elapsed since his day his views have received abundant support. Much interesting work is being carried on both in this country and abroad on the relations between climate and health. In Italy, for example, the Servizio Meteorico Sanitario conducts organised observations designed to find the connection, if any, between the varying climatic conditions and the abatement, or otherwise, of the symptoms of different illnesses. In the French desert post of Tamanrasset, in the Sahara, most interesting studies have been made

of the bodily effects of the very dry air upon newcomers and natives alike. It has been found that in summer digestive troubles are the rule, and show themselves always on the occasion of a marked variation in the humidity of the atmosphere, particularly when this is increased by the invasion of the district by moist air from the Sudan. Nervous symptoms, such as neuralgia, however, seemed to be started by the seasonal fall in night temperatures. An interesting point that emerged from these investigations was that persons whose perspiration remained normal (in most cases the secretion of sweat was either diminished or abolished altogether) escaped unpleasant symptoms.

Other interesting researches have been made in various parts of the British Empire. In Southern Rhodesia a very close relationship has been established between the rainfall of October to January and the number of Europeans admitted to hospital with malaria in the succeeding months. In the Punjab this connection is so well established that the occurrence of a generous monsoon is the signal for sending quinine by the ton to certain districts where it is known fever will follow the heavy rains. Adaptation of habits of life to prevailing conditions has greatly reduced the amount of death and sickness among white men in the tropics. The adoption of shirt and shorts and more temperate personal habits have done much for the health of the British soldier in India, who, in the olden days, not only often drank more than was good for him in any climate, but sweltered under the tropical sun in the same scarlet as he wore under the grey skies of home.

For the average healthy individual the best climate is one like that of the British Isles, taken as a whole,

with continuous moderate variations, so that all the organs and tissues are kept evenly at work. Invalids, however, require special climates, and their needs are as diverse as the complaints. Indeed, that is truc of the wholc question of the reaction of life to climate; it is as complicated and diverse as life itself.

Differences in climate also produce different mental reactions to the same cvcnt. Of this one instance must sufficc. In this country, with its adequate rainfall, the wet weather on Coronation Day, 1937, caused disappointment. In other parts of the Empire the feeling was different. A native of South Africa, whose home was in the rather dry interior of the Union, expressed his belief that the rain in London was a sign of the blessing of heaven on the new reign!

CHAPTER IX

The Atmosphere and Light

'By what way is the light parted?'

Job xxxviii. 24

There is a story told of a cockney tourist who, during an ascent of Ben Lomond, rather worried his guide as to the distance they could see. At length the Scot said that if his employer chose to wait he could show him something further still. So they waited, and, in due course, the guide solemnly pointed out – the rising moon.

That is only a story, but it does underline the great transparency, in the absence of smoke or cloud, of the atmosphere. Not only is the moon, 240,000 miles away, clearly visible, but, as proved by the wonderful photographs taken at Mount Wilson Observatory, the air allows passage to rays of light from island universes buried far in the depths of space.

This clearness of the air is, naturally, especially marked in districts away from big towns, and in such places as Norway and the remoter parts of Scotland visibilities of 50 miles or more are not the exception but the rule.

Under favourable conditions extraordinarily long views have been enjoyed. Thus the island volcano of the Peak of Tenerife has been seen from a distance of 190 statute miles, and the famous Himalayan peak,

Nanga Parbat (26,620 feet), is sometimes visible from certain points in the Peshawar district, 200 miles away. Again, despite the presence in the near foreground of the large manufacturing town of Clermont-Ferrand, Mont Blanc and a neighbouring peak are often to be seen from the observation tower of the Puy de Dôme, nearly 190 miles distant, appearing as 'immovable white clouds' between the peaks of a nearer range.

During the last 20 years much attention has been given to this question of atmospheric clearness or visibility, owing to its importance for aviation, and at observing-stations all over the world reports are made, based on an international scale, in which 0 represents a state of things in which objects are not visible beyond 55 yards, and 9 indicates an atmosphere clear enough for objects to be seen at distances greater than 31 miles. Generally speaking, the air is clearer away from towns, the smoke and dust of which not only cause an area of low visibility in their immediate neighbourhood, but may be carried by the wind for long distances. Even at Valentia, on the west coast of Ireland, where the visibility as a whole is usually very good, since it is situated 200 miles or more from industrial centres, a brownish haze is sometimes experienced, which has been found to be connected with air-currents from England or Northern Ireland. Visibility is also affected by the wind; the stronger the wind, as a rule, the clearer the air, for the eddy motion associated with wind helps to clear away the dust particles and the nuclei round which water vapour condenses to form mist. For the same reason good visibility often occurs on days when the presence of cumulus clouds shows that there are rising currents of air. That these

currents can carry up particles is shown by the rather disconcerting experience of two airmen who, when flying through a cloud above the Tochi Valley in Waziristan, suddenly began to weep with hay fever from the pollen that had been whirled aloft from the hillside 6,900 feet below, where the villagers were busy winnowing.

Visibility, also, is better above 3,000 feet, for most of the dust stays below that level; indeed, seen from above, the top of this dusty layer is distinct enough to form a sort of horizon. It is this clearness of the upper atmosphere that accounts for some of the long views to be obtained from mountain to mountain, and gives the reason why so many astronomical observatories have been built on mountain peaks, where they can be situated

> In regions mild of calm and serene air
> Above the smoke and stir of this dim spot
> Which men call Earth.

The source of the air also seems to have some influence on the kind of visibility connected with it. Thus, polar air newly arrived in this country from high latitudes, when it is still comparatively cold and dry, is generally very clear, but, as it becomes older, visibility in it deteriorates, probably because it picks up increasing amounts of the solid and liquid particles – suspensoids, as they are called – the changing quantities of which have such a great influence upon visibility. For the same reason visibility is often poor in the warm and moist currents of tropical air. In this country the conditions of illumination and suspensoids usually set up a certain amount of glare and diffusion of light,

with the result that the outlines of objects are seldom sharply defined. The general effect of this, coupled with the fact that weather in this country is always changing, is that our landscapes, with their softened outlines and shifting colours, are never the same two days or even two hours together, a state of things which has probably much to do with the rise of the great schools of landscape painting which are the particular glory of English art.

Suspensoids in the atmosphere may affect visibility, either by acting as a screen in front of the landscape or, if they are large enough, by reflecting light and causing glare. Or, if they are very small, they may weaken the light by scattering.

This last effect is the most important, for it not only affects visibility, but also prevents the stars being seen by day, save when the sunlight is cut off by something outside the atmosphere, as is the case during a total eclipse of the sun. The reports of stars being seen by daylight from the bottom of wells, etc., seem to be unfounded; the only star bright enough to overcome the glare from the atmosphere appears to have been the famous temporary star, or nova, that blazed out in Cassiopeia in 1572, and which is said to have rivalled Venus in brilliance. Venus can often be seen with the naked eye in full sunlight, especially when the sky is clear and her position is known. Also, many of the brighter stars may be picked up with the aid of a telescope.

Scattering is also responsible for the blue of the sky. When a beam of white light passes through a medium full of fine particles (e.g. soapy water), the various wave-lengths of which it is composed are unequally

scattered. The shorter blue waves are much more affected than the longer red ones. Therefore light passing *through* such a turbid medium loses many of its bluc waves, which are scattered *sideways*. The light from the sky, which is viewed across the direction of illumination, is thus very rich in blue rays.

The actual shade of blue observed in the sky is very variable. In fine, still weather, when the air is full of comparatively large particles, these latter reflect white light, which, becoming mixed with the blue, makes the sky pale. However, after these particles have been washed away by rain, the blue becomes much purer. For the same reason the sky is of a much deeper tint when viewed from heights of over 3,000 feet, at which elevation the dust layer next to the ground has becn left behind.

At very high altitudes, such as have been reached during stratosphere ascents, the colour of the sky deepens to black owing to the lack overhcad of particles to scatter light. During the flight of *Explorer II*, Major Stevens was able to compare the sky with the blue of the regulation U.S. army flag flown during the trip. When the balloon was in the stratospherc, there came a point where the blue of the sky was much darker than that in the flag; indeed, at the greatest height reached, it looked black, with just a trace of blue.

But if the light reaches the eye after passing through the atmosphere from the sun, or other source of illumination, it is another matter. This, in its passage through the atmosphere, has lost a proportion of its blue rays, and is thus richer in those longer ones that lie towards the red end of the spectrum. Even the mid-day sun, the rays of which take the shortcst

possible path through the atmosphere, probably looks yellower than it would on an airless world like the moon. Distant snow-fields also have, no doubt for the same reason, a yellowish tinge.

The blue of distant hills, which turns to purple when mixed with the red light of sunset, comes from the scattering of light, not only by dust, but by the molecules of air that occupy the intervening space.

This selective scattering of light by the atmosphere is behind the modern development of long-distance photographs, such as Plate V (p. 64), which shows the coasts of England and France from the air. The long invisible waves, just beyond the red end of the spectrum, are scattered even less than the red waves, and consequently penetrate much further through the atmosphere. Details of landscape, which in an ordinary picture would be either blurred or invisible, stand out sharply when taken with plates rendered sensitive to a band in the infra-red, through a special screen which cuts out nearly all the visible waves of light.

The yellow lamp-glasses that are used by some motorists are another application of the same principle. Owing to their colour they do not transmit many of the shorter blue waves, and lamps so treated give a light rich in the longer waves. Such a light in a smoke fog, the particles of which scatter blue light, escapes the wastage resulting from scattering, and becomes a real help. In a water fog, however, the droplets of which are too large to scatter light, such coloured glasses are of little use. The difference between the two types of fog is also shown by the fact that, seen through a water fog, the sun looks white, but seen through a smoke fog it looks red. This effect has seldom been better

described than in Gilbert White's description of the appearance of the sun during the summer of 1783. That year there were most violent volcanic eruptions both in Japan and Iceland, and the atmosphere in the northern hemisphere was laden with dust, producing, to quote White, '. . . a most extraordinary appearance unlike anything known within the memory of man. . . . The sun at noon looked as blank as a clouded moon, and shed a rust-coloured ferruginous light on the ground and floors of rooms; but was particularly lurid and blood-coloured at rising and setting.'

Even more sensational were the effects observed from a ship that happened to be in the neighbourhood of Krakatoa during the memorable eruption of 1883. The colour of the sun was seen to pass from reddish-brown to blue-violet, and then to bright azure. Nature was duplicating a laboratory experiment, in which a source of white light is viewed through a solution of thiosulphate of soda to which a weak acid has been added. The addition of the acid causes the precipitation of sulphur in fine particles. As the cloud of particles thickens the colour of the light becomes redder and redder, but at length a stage is reached when the red changes to blue. The reasons for this are too technical to be explained here, but there is some connection between the effect observed and the gradual increase in size of the sulphur particles.

Curiously enough, in those parts of the world such as China, Western Australia, and the Sahara, where the air is often filled with fine dust, particles of this critical size occur fairly frequently, for blue suns (and moons) are quite common in those districts.

Even under ordinary conditions the scattering of

light by the atmosphere affects the colour of the sun and moon when rising or setting, so that their disks appear more or less red, according to the number of particles, water-droplets, etc., present. The ancient and widely spread belief that a red and angry sky in the morning means bad weather – a belief which is often justified by experience – is supported and explained by the fact that, owing to there usually being not so much dust in the air in the early morning as in the evening, the red colour is caused by the presence of a large number of water-droplets. And the complementary idea that 'red sky at night' is a sign of fine weather is supported by the fact that its presence shows that there is a considerable area of fine, clear weather to the west, from which direction most European weather comes.

The most spectacular sunrises and sunsets occur when there are clouds, or when the atmosphere is laden with dust after a great volcanic eruption like Krakatoa in 1883, Mont Pelée in 1902, and, so far as places in the southern hemisphere were concerned, the outbreaks in the Andes in 1932. But the ordinary sunsets and sunrises in cloudless weather are not without points of beauty and interest, two of the most striking being the purple light and the shadow of the earth.

The purple light appears after sunset or before sunrise as a cloud of rosy light which is often furrowed by fanlike beams of bluish shadows, cast either by distant clouds or mountains, an appearance which seems to have been the origin of the famous epithet 'rosy-fingered' applied to the dawn in the Homeric poems. Sometimes, indeed, it is possible to identify the source of the shadows. Once, during a long spell of fine weather in the United States, when it was known there

was not a cloud in the sky over an area of thousands of square miles, the purple light was furrowed, evening after evening, by streaks of shadow, the constancy of which, both in position and number, forced the observers to the conclusion that what they were seeing were the shadows cast across the sky by the Rocky Mountains hundreds of miles to the west.

Under favourable conditions these rays can be traced right across the sky.

The earth itself also throws a shadow on the atmosphere, which appears after sunset on the eastern horizon as a dark bluish arc, edged by the reddish 'counterglow' which is caused by the sun lighting up the atmosphere to the east by rays tangential to the earth. As the sun sinks, the shadow rises in the heavens till its boundary becomes indistinct owing to the change in the angle of illumination. The reverse happens at sunrise, when the shadow and counterglow are seen sinking in the west, to disappear at sunrise. Observation of the shadow is difficult in towns, and it is best seen in the country, particularly where there are wide horizons, and by the seaside or at sea. Some of the most detailed studies of the shadow have been made at the Observatory of Ksara, in Lebanon, which show, amongst other things, that the appearance of the shadow varies according to the state of the sky to the westward, and can therefore be used as an aid to making local weather forecasts. For instance, low clouds which are rather close give blue bands towards the east which are not met with in the purple light in the west, but, if they are far away, the shadows only appear in the west.

It is the shadow of the earth and the purple light that contribute largely towards that crowning glory of the

high snows, the Alpine glow. As the sun sinks the peaks change from white through yellow into blazing red. Then, as the earth shadow rises, the colour fades and the peaks assume a curious dead-white hue, but, after a while, light up again with a deep rosy flush, called at Chamonix 'the resurrection of Mont Blanc,' which is caused by the reflected glow of the purple light.

Another interesting and fascinating aspect of sunset or sunrise in the mountains concerns the shadows thrown by the peaks. A recent expedition to the Andes saw the shadow of Aconcagua cast on the haze like a huge ghostly pyramid, and even more interesting was the experience of a watcher on the Monch near Interlaken, who twice saw the shadow of the summit outlined in dark blue against the red counterglow, its tip appearing to end just at the edge of the shadow of the earth.

Not all the happenings at sunrise or sunset are due to scattering. Manx folklore contains much about the *soilshey-bo*, or 'living light,' a mysterious emanation from the sun which, if it fell upon certain herbs, gave them almost miraculous healing powers. This is almost certainly a reference to what sailors call more prosaically 'the sun putting out his sidelights,' for, in fine clear weather, the first sight of the rising sun, or the last glimpse of the setting sun, may be brilliant green like the starboard light of a ship. This effect is due to the refraction of the rays from the edge of the sun by the dense lower layers of the atmosphere, which results in the blue and green rays being bent more than the red and yellow, so that they can be seen while the others are out of sight below the horizon. Usually,

even in clear air, the scattering is enough to suppress the blue rays, so the appearance has the colour that has given it its name of the 'green flash,' but, with very clear air, the green has been seen to change to blue, and even to a 'glorious violet,' at the last minute.

There is also a 'red flash' to be seen when the lower edge of the sun is just disappearing at a well-defined horizontal edge of cloud near the horizon. The planet Venus has also been observed to set as a spectrum, red below and green above.

Refraction also affects the time of sunrise and sunset. When rays of light pass from one medium to another they are bent out of the straight, so when they enter the atmosphere from empty space they are turned to one side; therefore the heavenly bodies do not appear in their real positions, but a little to one side, a fact for which allowance is always made in astronomical observations. The amount of refraction is greatest for a ray of light coming from the horizon; indeed, there it is so great, and changes so rapidly with height, that when the sun and moon are in that position the light coming from the top of their disks is less refracted than that coming from the bottom, giving the whole disk a flattened appearance.

The normal amount of refraction at the horizon is just enough to raise the disks of the sun and moon right above the skyline when, actually, they are just below it.

Owing to the fact that atmospheric refraction is so closely connected with the density of the air, its amount is subject to sudden changes, which, frequently, have rather dramatic results. One of the most cherished traditions of the Celtic races is that concerning the mystic

island valley of Avilion,
Where falls not hail or rain or any snow,

and which – so say lovers of old lore – can sometimes be seen against the sunset, after long and patient gazing from the westernmost shores of Ireland or Scotland. Thirty years ago, the 'Green Meadows of Enchantment' were still an article of faith among the seamen of south-west Wales, and it has been suggested that the belief in this mysterious western isle was fostered by some of the freaks of refraction. For instance, when the lower layers of air are colder than those immediately above – i.e. when there is an inversion – the presence of this denser layer exaggerates the normal refraction to such an extent that islands, coastlines, etc., which are usually hidden by the horizon are lifted into view. Indeed, the finest example on record of this sort of thing occurred in British waters. In ordinary circumstances, the French coast, 45 miles or so distant, cannot be seen at all from the sea-front at Hastings, and only very faintly, in clear weather, from the hills near the town. But during the evening of July 26th, 1797, the coast of Picardy was seen so clearly from the shore that the fishermen could recognise landmarks known to them near Boulogne and St. Valery, and, through a telescope, Dr. W. Latham, F.R.S., who, fortunately for science, was staying at Hastings, could see the French fishing-boats lying at anchor and distinguish the different colours of the houses and the ground. In this instance there are no detailed records of the weather conditions, but more recent observations show that this unusual refraction is associated with great differences of temperature between the sea and the air. In one such case, in the Gulf of Suez, when the lights on certain

capes were seen at twice their usual distances, the temperature of the sea was 7° to 10° below that of the air.

Unusual refraction of this kind saved the lives of Sir Ernest Shackleton and his party on their return from their unsuccessful attempt to reach the South Pole in 1909. By February 23rd of that year they were starving, and everything depended upon their reaching in time a certain food depot. There were no tracks leading to this particular dump, and it is very likely that the explorers would have missed it entirely had not, early one morning, the depot flag been sighted. It had been lifted above the horizon by refraction, and remained visible just long enough for an accurate bearing of its direction to be taken.

In Canada unusual refraction is put to practical use. The Meteorological Service is able to give warning of the weather conditions favourable to its appearance, so that observers at survey stations which are usually out of sight of one another can prepare to take observations during the time that their respective posts are intervisible.

Sometimes the temperature inversion is some distance above the ground. Such was the case when the photograph in Plate XIa (p. 210) was taken, in which the town is seen twice, first by rays proceeding direct to the camera, and then, secondly, by rays that have been bent downwards through the layer of colder and denser air above, producing an inverted image above the object (superior mirage). In this particular instance the image formed was so clear that it is said that wheeled vehicles were seen moving upside down.

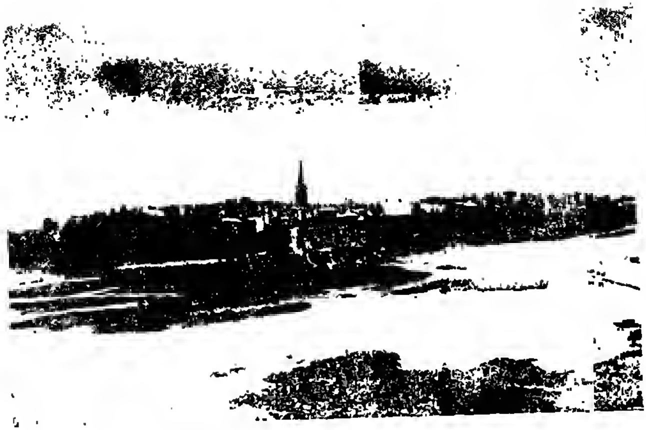
An inversion layer at no great height above the

observer gives rise to the most curious distortions of the shape of the sun and moon when on the horizon. One observer described the setting sun as resembling 'a gigantic red-hot rivet,' and another saw the disk assume first the shape of a mushroom and then that of a bowler hat.

Desert areas afford excellent opportunities for studying the vagaries of atmospheric refraction. During the night the strong radiation from the ground sets up an inversion, so that, at sunrise, one can see far beyond the normal horizon. Many parts of the Anglo-Egyptian Sudan are as flat as the proverbial pancake, but, during the dry season, the refraction at dawn is such that the observer has the impression that he is standing at the bottom of a valley, with rising ground all round. As the sun rises in the sky the ground warms up, the inversion breaks down and the landscape begins to flatten out. In a few hours, indeed, the opposite condition to an inversion is created, and the air next to the ground, instead of being cold, is very warm.

One result of this state of things is shown in Plate XIb, which was taken in the famous Death Valley, California. In the background there appears to be a sheet of water in which the distant hills are reflected. Rays of light, descending at the appropriate angle from the sky, have traversed the layer of hot and thin air next to the desert, and have been bent upwards. Therefore, a patch of sky appears projected on to the ground, and gives the impression of water. The illusion is aided by the shimmering of the heated air as it pours upwards from the ground, and by the fact that suitably placed objects may be seen twice; first by horizontal rays that proceed straight to the observer, and secondly by rays that have

PLATE XI



a. Superior Mirage. St. Malo, August 15, 1902 (p. 209)
By courtesy of Messrs. George Newnes, Ltd.

b. Inferior Mirage. Death Valley, California
By courtesy of the U.S. Weather Bureau

PLATE XII

a Sound ... th...

b Photograph of the V shaped compression waves from a high speed bullet. These shock waves gives rise to the whine of the projectile (p. 218)

From a photo by Professor W. Cranz

passed through the mirage layer and have been bent upwards, producing an inverted image that looks as if it were reflected in water (Fig. 19).

The realism of this sham water, which vanishes when approached, owing to the change in the angle of vision, has made this kind of mirage the type of deceit and illusory hopes. Thirteen centuries ago it was recorded in the Koran: 'The works of the unbelievers are like the mirage [*serab*] on the plain; the thirsty man takes it for water till he comes and finds that it is not.' The

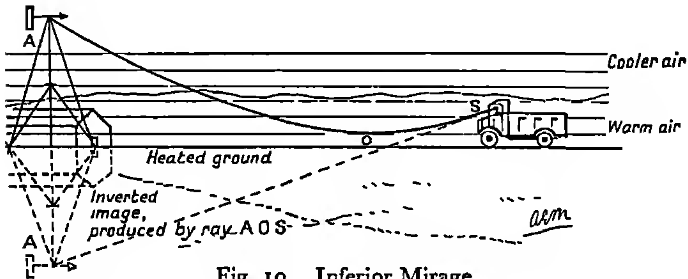


Fig. 19. Inferior Mirage

Arabs of to-day call the mirage *Bahr el Shaitan*, or 'The Sea of Satan.'

About 50 years ago settlers were coming into Kansas. One of these has told how, on arriving at the railhead, he engaged a hack-driver to drive him to his new home. The man charged the exorbitant figure of a dollar a mile, explaining that they were obliged to ford a lake which could be seen in the distance. And, as he insisted upon payment in advance, his passenger had parted with his money long before he had found out that the lake was no lake but a mirage. This kind of mirage is often accompanied by restriction of vision. The long range of visibility that accompanies the early

morning inversion in the Sudan is replaced, by noon, by a horizon narrowed to just over half a mile, though trees may be seen four miles away. The same effect is also noticed at sea when the water is warmer than the air. In Captain Cook's log for December 31st, 1773, it is recorded that an east wind blew a snow-squall over the ship. Immediately a large iceberg in front of the horizon was seen *behind* the skyline. After the squall had passed, the berg was seen in front of the horizon as before. An even more remarkable instance of the narrowing of the horizon occurred in 1784. One afternoon great excitement was caused amongst Maltese sailors and fishermen by a report that a new island had arisen in the channel between Malta and Sicily, and several seamen set out to take possession of it. However, in about half an hour's time the 'island' began gradually to increase in height, and, before long, it assumed its true aspect as Mount Etna and the coast of Sicily, which are normally visible from Malta, but which, through some freak of refraction, had been so optically lowered that only the summit of the mountain remained visible.

Occasionally a mirage may be seen by looking along a wall that has been well heated by the sun. To an eye close to the surface passers-by appear to be reflected sideways. This effect is due to refraction by the layer of warm, less dense air close to the hot wall.

It is not always the case, however, that the layers of dense and less dense air are arranged so regularly. Indeed, the atmosphere is never really of uniform density throughout; it is full of pockets and layers of air that vary greatly amongst themselves in density. These pockets and layers, which, according to the late

Professor Exner of Vienna, are from half an inch to eight inches in length, act as so many convex and concave lenses, both dispersing and collecting the rays of light. These pockets are continually being moved about by the wind, so that the image of a star, seen through the atmosphere, is never steady, but is constantly moving about and altering in brightness. And, since the light from the stars is made up of waves of different lengths, a separation of colour takes place, giving rise to the effect described by Tennyson in the lines:

> . . . and fiery Sirius alters hue
> And bickers into red and emerald.

The coloured scintillations of Sirius are particularly prominent because not only is that star the brightest in the sky, but, in these latitudes, it is always comparatively low in the heavens, and so is seen through a great thickness of air.

The planets seldom twinkle. Unlike the stars, they are near enough to the earth to appear of a definite size, instead of as mere points of light. Thus, every point on their surface twinkles independently, with the result that the multitude of scintillations cancel each other out, and a steady, bright disk is shown. Planets, however, twinkle when close to the horizon, and, in the case of Venus, may render the streakiness of the atmosphere actually visible. Thus, in 1602, Kepler was observing Venus, which was twinkling violently. He happened to look at a white wall, on which fell the light from the planet, and saw thereon undulations like smoke. These were the shadows thrown by the streaks and pockets in the atmosphere. To the same cause are due the 'shadow bands' which dance across

the landscape just before an eclipse of the sun becomes total, and all the light comes from a very narrow crescent.

The streakiness in the atmosphere is the cause of the quivering of the air on a hot day, as the air, heated by contact with the ground, rises through the cooler layers. In tropical countries this shimmer is a great hindrance to survey work. In the Sudan, for instance, accurate measurements are not possible after 9 a.m. local time.

But this atmospheric streakiness often occurs on a large scale, and produces some of the weirdest and most striking atmospheric phenomena. In one of the romances that were so popular in Italy during the Renaissance, and which were introduced to English readers by Thomas Bulfinch in his *Legends of Charlemagne* (1863), it is related that the paladin Orlando entered the magic garden of the Fairy Morgana in search of some knights that she was holding captive. He found Morgana asleep, and was about to seize her, when, all at once, his attention was distracted by a marvellous array of palaces, towers, colonnades, and other architectural wonders. While he stood gazing at the spectacle, it slowly faded away and disappeared. In a note on this episode Bulfinch says, 'This is a poetical description of a phenomenon said to be exhibited in the Strait of Messina between Sicily and Calabria.' In this part of the world the unstable condition of the atmosphere causes the most extraordinary distortions, towerings, and multiplications of the images of buildings, cliffs, etc. For instance, from the Calabrian shore an observer once saw, apparently reflected on the surface of the sea, a series of pillars that were so huge that their tops and bottoms were

invisible. From the position of the image, the observer concluded that this fantastic colonnade was merely the distorted reflection of the viaduct on the Messina–Gesso railway.

This type of mirage is not confined to the neighbourhood of Sicily. It has often been observed off other coasts, especially those of enclosed waters. In such localities there are likely to be great differences of temperature in the air over short distances. Land heats up much quicker than water does, so that on a hot day the air over the sea soon is colder, and, therefore, denser, than that over the neighbouring land. If there also happens to be a breeze, there is much mixing of layers of air of different densities, and much passing of tongues of air from one layer to another.

This mixing of air currents may take place in the open sea. In 1930 the most extraordinary distortions of the image of a passing cargo-boat were observed by passengers on the R.M.S. *Mauretania.* As the tramp drew abeam of the liner she appeared to turn turtle, and all that could be seen of her was a long oblong object minus masts, funnel, or smoke. So complete, indeed, was the illusion of disaster that a woman shouted, 'She's gone !' But she soon reappeared in the shape of a rectangular tank split along the centre. Then two ships were seen, an inverted one in the air directly above the other. And so the phantasmagoria went on, for until the tramp disappeared astern, about an hour later, she never appeared normal again.

On Loch Ness, the loch steamer has been seen (apparently) to leave the surface of the water and sail up into the sky.

Mirage of the Fata Morgana type reaches its greatest development in the polar regions. The open lanes of water that occur amongst the ice-floes may, on occasion, be about 30° F. warmer than the air, so there is much mixing of warm and cold air. Sir Ernest Shackleton has described the almost unnerving effect of the constant play of mirage. Icebergs would be thrown up into the sky as great golden and white cities of oriental aspect. Vague smudges would appear in the sky and meet, till the ship was surrounded by lines of shining snow-cliffs, washed at their bases by spectral seas in which they were faithfully reflected. Though the Antarctic is not favoured in many ways by nature, yet the atmosphere gives it beauties of its own. Electric discharges in the upper air deck the night skies with the streamers and curtains of the aurora. Ice-crystals in the lower atmosphere refract light, and cover the heavens with prismatic circles and arcs. And, at the level of the sea, air masses of different temperatures and densities bend light in an irregular fashion, and transform the polar wastes into the magic realm of Morgan le Fay !

CHAPTER X

The Realm of Sound

'You must understand he goes but to see a noise that he heard'

Midsummer Night's Dream, iii. 1

There is many a true word spoken in jest. Had Shakespeare been in the company of that distinguished and daring student of volcanoes, Professor A. Perret, during the eruptions of Vesuvius and Etna that took place respectively in 1906 and 1910, he would have discovered that what he wrote as a joke was actually taking place before his eyes. At every explosion of the volcano he would have seen a thin ring of light flash upwards and outwards from the crater, and he would have heard Professor Perret's explanation of these mysterious rings as visible sound-waves.

All sound, however originated, whether by the human voice, or a musical instrument, or an explosion, consists of a pulse, or succession of pulses, of compressed air separated by regions of rarefied air travelling outwards from the source of disturbance at the speed of roughly 1,100 feet per second. And, as the density of the air affects its power to refract light, the powerful waves set in motion by the explosions of a volcano, or even by the discharge of heavy artillery, are, in favourable circumstances, rendered visible as curved lines of light and shade sweeping across the sky, a sight that was by no means uncommon in France between 1914

and 1918. Indeed, one observation of this nature during the war period confirmed Professor Perret's explanation absolutely, for the observer heard the report of the distant gun at the very moment that the visible wave reached his feet.

In the same way the shadow of the compression wave caused by the report of a pistol (Plate XIIa, p. 211) can be thrown upon a photographic plate, and most instructive pictures demonstrating the reflection, refraction, diffraction, and interference of sound-waves obtained, for in many respects waves of sound behave as do those of light. They are, however, very much larger, their length being measured in feet instead of thousandths of an inch, and they are different in character. Sound-waves are longitudinal, i.e. the separate particles move backwards and forwards *along* the direction of motion, whereas waves of light and of water are transverse, i.e. the movement is *across* the direction of motion of the wave as a whole.

The first attempt to calculate the speed of sound was made by Newton, who, in 1686, published a formula which, however, when compared with the results of actual experiments, gave a value 15 per cent too low. Though Newton made several attempts to explain the discrepancy, the mystery was only solved 130 years later, when the great French astronomer, Laplace, showed that Newton, in his calculations, had failed to allow for the changes in the temperature of the air due to the rapid compression and expansion caused by the passage of the sound-wave.

The earliest measurements of the speed of sound were made by observing the interval between seeing the flash and hearing the report of a distant cannon. Light

travels so fast (186,000 miles per second) that, over the distances involved, the flash of the gun may, for practical purposes, be said to be seen at the moment the discharge takes place, whereas the sound will take a measurable interval to travel to the observer.

This method is now of historic interest only, being superseded by electrical methods. A special hot-wire microphone is used, and the instants of the firing of the gun and of the arrival of the sound-wave are recorded on a moving film. In Fig. 20 (p. 229) the figures along the top of the record show the number of seconds that have elapsed since the firing of the gun.

In the days when the cannon method was still in vogue, one very peculiar incident occurred which has never yet been properly explained. In the winter of 1821–2 Captain (afterward Sir) W. E. Parry and the Rev. G. Fisher conducted a series of experiments of this kind at Winter Island, in the Canadian Archipelago. A base line, about a mile in length, was drawn on the sea-ice, at one end of which was stationed a gun-crew in charge of a six-pounder gun, while at the other stood Parry and Fisher. When the officer at the firing-point was sure everything was ready, he gave the order to fire, and the observers noted independently, by means of chronometers, the interval between flash and report.

Usually the word 'Fire' could not be heard by the observers, but, on the night of February 9th, 1822, when 15 rounds were fired, not only was the word of command heard several times, but it reached the ears of both Parry and Fisher out of place: it was heard about one beat of the chronometer *after* the report of the cannon. The temperature on this occasion was

low, but not unusually so for the locality; the barometer, however, stood at the record low level of 28·84 inches. As atmospheric pressure has no effect upon the speed of sound, this low barometer reading cannot explain what was observed. The 'singular circumstance,' as Fisher called it, remains to-day, as it did in 1822, entirely unaccounted for.

The speed of sound in dry air at freezing-point is 1,085 feet per second. To find the actual speed at any given moment, corrections for temperature and moisture, both of which affect the density of the air, have to be made. Generally speaking, 2 feet per second have to be added for every 2° F. (nearly) rise of temperature above freezing-point.

It is upon the speed of sound in air that modern sound-ranging depends. As used in military operations, a sound-ranging set consists of six microphones, spread out on a base line about 9,000 yards long, and some 3,000 yards behind the front line. Each microphone is connected with one string of an Einthoven galvanometer. Permanent records are obtained by projecting the shadows of the strings upon a moving film upon which time-marks are also recorded.

When this type of sound-ranging is used it is not necessary for the gun to be visible. During the war of 1914–18 the practice was for the whole apparatus to be connected to an advance observation post. When the officer at the O.P. heard the report of the enemy gun the range of which was required, he pressed a key which started the recorders at headquarters. When he considered that the sound-wave had passed over the microphones, he stopped the apparatus in a similar manner.

The kind of record obtained is shown in Fig. 20 (p. 229), which was made during peace-time investigations at Cardiff. So long as the microphones are inactive the strings of the galvanometer are still, and their shadows trace a straight line on the film. Now, the microphones used in this sort of work consist of metal boxes of six to seven pints capacity, with small necks, across which are stretched grids of fine platinum wires, kept warm by electricity. When the sound-waves reach these instruments, the wires are momentarily cooled, with a resulting increase in their power to conduct electricity. The result of this is to produce a momentary electric current in the corresponding strings of the recorder at headquarters, which strings are displaced and vibrate, so that kinks appear on the continuous lines on the film. The time-marks show the exact time of arrival of the sound at each microphone; from Fig. 20 it will be seen the wave arrived at the three microphones, A, B, and C, at roughly half-second intervals.

The actual position of the gun was arrived at by means of a diagram. Half a dozen microphones are used for greater accuracy, but three only are requisite. Let the three be called X, Y, and Z. A circle is drawn round Y having a radius equivalent to the distance sound would travel in the intervals between the times that X and Y record the sound. Another circle is drawn round Z of which the radius corresponds to the distance sound would travel in the interval between the X and Z observations. A third circle is then drawn, going through X and touching the other two; the source of the sound should be at the centre of this circle.

In practice, corrections have to be made for wind,

temperature, and moisture. During the war, guns 3 to 10 miles from the microphone could be located to within 100 yards.

An interesting post-war application of sound-ranging is that used at the Cumbrae talking beacon. During fog, the Cumbrae Lighthouse on the Clyde sends out its name by radio-telephone and, simultaneously, speaks it through a fog-horn. Any ship in the neighbourhood may estimate its position by noting the difference in time between the arrival of the broadcast and that of the spoken word.

It was found during the war that the sound-ranging apparatus did not work very well when the wind was blowing towards the enemy lines, an effect due not so much to the wind itself, but to the fact that the speed of the wind increases with height. The result of this is that the sound at ground level travels much faster than it does higher up, and the wavefronts are bent upwards so that they may pass right over recording instruments sited on the ground. On the other hand, sounds travelling with the wind are kept down to the ground.

The distribution of temperature also affects the travel of sound. Those interested in grand opera may have sometimes speculated how, in Act III of *Aïda*, the Princess Amneris, who is supposed to be at her devotions in the temple, would be able to overhear enough of the lovers' conversation outside to be able to interrupt in the dramatic manner that she does. Now it is a curious fact that though probably both librettist and composer were unaware of it, the setting, designed no doubt for purely romantic reasons, for this act, implies meteorological conditions that would favour

the travel of sound. The stage directions read 'Night, stars, and a bright moon,' a state of affairs often accompanied, especially in Egypt, by a strong temperature inversion which makes the sound-waves travel more quickly above than close to the ground, so that the upper part of the wavefront is bent downwards. The effect of this, combined with reflection from the ground, is to concentrate the sound along the surface; hence on still, clear nights, sounds carry far.

The fact that fogs are always accompanied by an inversion of temperature accounts for the fact that sounds carry so well in thick weather. In such a case, too, the temperature of the air is more uniform than it often is in clear weather, so the waves are not broken up by reflection between air-layers of different density.

On hot summer days, when there is a layer of warm air next to the ground, hearing conditions are often as bad as those in an inversion are good. With the warmer air next to the surface, the wavefront travels fastest near the ground and slower in the cooler air above with the result that it curves upwards and outwards away from the ground. In summer-time, too, when convection is very active, the air becomes full of currents and masses of air of different densities, with the result that the sound-waves become so bent and broken that they only carry comparatively short distances.

The combined effect of wind, temperature, and humidity on the passage of sound through the air is very complicated, and is responsible for many curious freaks and vagaries such as were frequently noted during the war period. For instance, during the Zeppelin raid of May 23rd–24th, 1917, three independent and well-trained anti-aircraft detachments

stationed near Hatfield reported that airships were nearly overhead, though in reality there was no enemy aircraft within 25 miles. The Board of Trade 'General Notices to Mariners' contain the following warnings about fog-signals:

'1. Fog-signals are heard at greatly varying distances.

'2. Under certain conditions of the atmosphere, when an air fog-signal is a combination of high and low tones, one of the notes may be inaudible.

'3. There are occasionally areas around a fog-signal in which it is wholly inaudible.'

The effect mentioned in the second paragraph may probably be due to the existence of eddies in the lower layers of the atmosphere, which, together with local variations in the temperature, cause scattering of the sound-waves; those of shorter wave-length would be more affected than the longer and lower-pitched ones.

The refraction or bending effect on the waves of sound through the wind and/or temperature at different levels may be definite enough to create what has been termed an 'acoustic horizon.' This, in some cases, may be well above the real horizon, with the result that an aeroplane may be seen some time before it is heard, for the sound of the engines will only reach the ear of an observer on the ground when the aircraft has crossed the acoustic horizon. Sometimes, however, the scattering effect of the atmosphere on sound-waves mentioned in the paragraph on fog-signals may be such that the aeroplane can be heard faintly just before and after it crosses the acoustic horizon. These sounds from beyond the acoustic horizon are particularly difficult to locate by means of the direction-finding devices that play such a large part in anti-aircraft measures.

Most direction-finding apparatus, whether for use in air or water, is based upon the model provided by nature, viz. a pair of ears, for it is because of these appendages that we are able to judge of the direction of a sound, since the sound enters one ear a fraction of a second before it enters the other. For direction-finding of sounds in air, two pairs of collecting-trumpets are used; these are placed several feet apart, and thus the binaural effect is magnified. Each pair of trumpets is connected by tubes to the ears of an observer, and each pair has a different movement, so that not only the direction of the sound can be obtained, but also the angle of its elevation above the horizon. During the time that the apparatus is searching for the source of sound, each observer will hear the sound more strongly in one ear than in the other, but when the trumpets are so adjusted that the sound in both ears is of equal intensity, then the apparatus is pointing towards the position of the aeroplane. Under favourable conditions of listening, an accuracy of two or three degrees is possible, but in practice matters are complicated, not only by atmospheric conditions, but by the great speed of modern aircraft, owing to which the aeroplane, by the time the sound has reached the detector, will have changed its position to an appreciable degree. Thus the real position of the aeroplane will always be somewhat in advance of the position found.

The bending of sound-waves by the atmosphere may have other very interesting results. On June 2nd and 4th, 1666, during the Dutch War, Mr. Samuel Pepys wrote in his diary as follows:

'. . . I went on shore with Captain Erwin at

Greenwich, and into the Parke, and there we could hear the guns from the fleete most plainly. . . . In the evening come up the river in the Catherine yacht, Captain Fazeby, who hath brought over my Lord of Aylesbury and Sir Thomas Liddall with a very pretty daughter, and in a pretty travelling dress, from Flanders, who saw the Dutch fleete on Thursday, and ran from them; but from that hour to this hath not heard one gun, nor any news of any fight. . . .

'4th. So walking through the Park, we saw hundreds of people listening at the Gravel-Pits, and to and again in the Park to hear the guns. I saw a letter dated last night from Strowd, Governor of Dover Castle, which says that the Prince (Rupert) come thither the night before with his fleete; but that for the guns which we writ that we heard, it is only a mistake for thunder; and so far as to yesterday, it is a miraculous thing that we all Friday and Saturday and yesterday did hear every where most plainly the guns go off, and yet at Deal and Dover, to last night they did not hear one word of a fight, nor think they heard one gun. This added to what I have set down before, the other day, about the Catherine, makes room for a great dispute in philosophy, how we should hear it and they not, the same wind that brought it to us, being the same that should bring it to them: but it is so !'

Mr. Pepys does not say if he ever consulted any of his learned colleagues in the then newly founded Royal Society about the matter, but it seems likely he did not; at any rate, no further notice seems to have been taken of the phenomenon until 1887, when the Government report on the great eruption of Mount Tarawera, in the North Island of New Zealand, remarks:

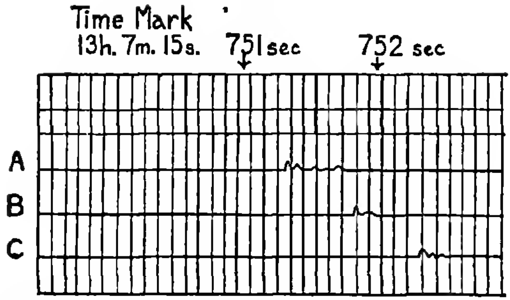
'It is noticeable that the people who survived and were nearest to the seat of the eruption – viz. those at Wairoa – failed to hear the loud detonations which were heard at Hamilton, Te Aroha, Christchurch (425 miles away), Nelson . . . and other places. . . . It is strange that the reports were not heard at Lichfield, only about 40 miles to the west, while they were heard distinctly at Waotu, about 6 miles further off. Mr. Howard Jackson suggests that the waves of sound were deflected by the eastern side of the Paterere plateau and so carried over the heads of the people of Lichfield.'

Mr. Jackson's suggestion, though not quite correct in all details, contains the germs of truth. Though Professor von dem Borne had collected details of the travel of sound following a great factory explosion in Westphalia in 1903, it was the experiences of the war period 1914–18 that really excited general interest in the matter. For instance, in January 1917 a munitions factory blew up at Silvertown, East London. The sound of the explosion was heard in the Home Counties, and in Norfolk and South Lincolnshire, but not at all in the intermediate counties of Cambridge, Huntingdon, and parts of Essex and Suffolk. Furthermore, an enterprising amateur living near Chelmsford kept a diary in which he noted, day by day, whether or not the firing on the Western Front could be heard, discovering thereby that sounds from the battlefields only reached eastern England in the summer. At the same time Continental meteorologists were making the same sort of observations, and they found that the sound of gunfire in France and Flanders was best heard over western Germany in the winter months.

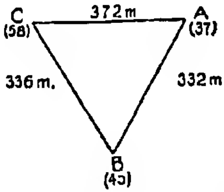
Observations such as the above excited such interest

that when it became necessary to dispose of surplus ammunition after the war by blowing up the dumps, the travel of the sound-waves was investigated by asking members of the public and others to listen for the reports. The same procedure is still followed in this country on the occasion of reviews and fleet exercises that involve the firing of salvos from the heavy guns, but most of the research is now carried out with the aid of equipment similar to that used in sound-ranging. The air-waves produced by the firing of guns on the Woolwich and Shoeburyness ranges are picked up by hot-wire microphones, installed in various receiving-stations distributed about the country, and recorded on a moving film which can be developed afterwards and studied at leisure. Exact timing is ensured by arrangements through which the officer who fires the gun at the same time transmits a signal which is broadcast by the B.B.C. The study of such records shows that, instead of travelling direct from the gun to the microphone, the waves make quite a long detour by way of the upper atmosphere. Thus, these observations of sound-waves form, at present, the only direct means we have of investigating conditions at heights, say, of 20 miles. That is, of course, the justification for all the time and trouble devoted to these matters.

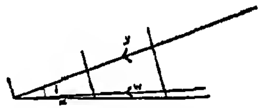
Fig. 20 shows the kind of record obtained during such experiments. The thick lines on the chart are at half-second intervals; the figures show the number of seconds that have elapsed since the discharge of the gun at Woolwich. Below are the records of the three microphones which are arranged approximately in an equilateral triangle. The chart shows that the intervals between the reception of the waves by A, B, and C



Section of Microphone Record: 3 Microphones.
Time of Passage to Microphone A = 751 sec.
Intervals between Microphones, AB = ·51 sec., AC = 1·02 sec.



Lay out of Station at Cefn Mably.



Approach of an Airwave.
(Vertical Section).

Dip of CA = α = $3\frac{1}{2}°$. Velocity of Sound at 295°A = v = 343·9 m/s.

sec (i + α) = v.Δt/CA = 1·06 ; i + α = $19\frac{1}{2}°$.

i = 16°, w = v sec i = 358 m/s.

Fig. 20. Microphone record of sound waves.
(*Q.J.R. Meteor. Soc.*, 1935)

are equal, which indicates that the waves have reached Cardiff, where the record was taken, from the east. It was also worked out that the waves descended at an angle of 16° and travelled at about 1,160 feet per second.

Owing to the way in which temperature decreases in the lower layers of air, waves of sound are usually bent upwards, so that at a certain distance from the gun or other source of sound they pass overhead and are not heard, thus giving rise to a zone of silence. (It is noteworthy that the only two places in the zone of silence where the sound of the Silvertown explosion is believed to have been heard were on high ground.) But the sound-waves do not mount up indefinitely; it seems that at a height of 20 miles or so they encounter a layer of air in which the temperature is as high as, or even higher than, that usually prevailing on the surface of the earth, which bends them down to the ground again. At this height, too, the sound-waves meet a steady wind, which blows from the east in summer and from the west in winter, which is the reason why the guns in Flanders were heard in the summer in England, and in the winter in Germany.

Sometimes there is a double or triple zone of silence, which indicates that the sound-wave, after coming down to earth, has been reflected up again. For instance, in December 1928 waves from an explosion in Germany were received at a station about 360 miles away after three reflections.

In the case of very violent explosions, such as the great outburst of Krakatoa in 1883, the sound of which carried 3,000 miles, and that of the great Siberian meteor of 1908, there is no zone of silence.

Not all the energy of an explosion goes into producing sound-waves which are audible to human beings. Much force is expended in giving rise to waves which, though of the same nature as sound, are too long (more than 50 feet) to affect the human ear, though

they may show their presence by rattling, and sometimes breaking, windows, and sometimes by being recorded on sensitive barometers. These infra-sonic waves seem, however, to be sensed by some of the lower animals; it has been demonstrated that they are felt by insects, and pheasants also seem to be conscious of them. There are many instances on record of these birds being disturbed by firing which was inaudible to human listeners. For instance, the late Rev. J. M. Bacon has told how, evening after evening, he would go out on the lawn of his Berkshire home and listen hard for the report of the evening gun at Portsmouth, but without avail. But, in the neighbouring preserves, the pheasants, just after the hour, would give a startled flutter. Why these birds should be so sensitive to infra-sonic waves is not known. The writer is inclined to think that there is some connection between the faculty and the fact that the pheasant is a native of an earthquake region – the Caucasus – and it would obviously be of advantage to a species to be able to sense the vibrations that come just before the shock. In this connection, too, there may be some scope for anyone wishing to undertake some original research work, for, according to the generally accepted theory of hearing, the power of the pheasant to appreciate these long infra-sonic waves should be associated with the presence in the inner ear of fibres longer than those in the same structure in man.

Very powerful air-waves were associated with the great eruption of Krakatoa, the culminating outburst of which gave rise to a tremendous wave in the atmosphere that travelled from the volcano to its antipodes four times, and back to the volcano again three times,

before it finally died away. Again, the fall of the Siberian meteor set up atmospheric disturbances which devastated the immediate neighbourhood and were recorded on delicate recording barometers all over the world. For 37 miles round the place where the meteor fell the forest was blown down. In a town 40 miles away one witness told the Russian scientist Kulik, who investigated the matter, how he had been thrown off his feet a distance of seven feet or more; and another related how the windows were smashed inwards, and the door of the Russian stove torn out, so that it sailed across the room into a hammock – effects, as pointed out by Dr. F. J. W. Whipple, due to the arrival first of a pressure wave and then of a suction wave. Another witness said he knew an old Tungus tribesman whose brother was deafened by the explosion, a result probably of the impact of the intense pressure wave on the eardrums. When heavy guns are fired it is the practice of the men to yawn, by so doing they establish communication through the Eustachian tube between the mouth and the middle ear, and thus allow the pressure wave from the gun to enter. If they did not do this, the eardrum would probably be ruptured, since the explosion wave would fall on one side of it only.

Generally speaking, however, the energy of ordinary sound-waves is very small, and, according to the estimate of Dr. Kaye, if everybody in Greater London shouted at the top of his or her voice, the power generated would be in the neighbourhood of one horse-power.

There is, of course, much more in hearing than the mere reception of vibrations, for, as is the case with all the senses, there is a subtle mental side, which may

for ever elude exact description. But, on the mechanical side, the ear may be regarded as a very delicate instrument for receiving and transmitting vibrations. These vibrations, after passing along the short canal leading from the exterior, impinge upon the eardrum, which is a stretched membrane of such delicacy that it can respond to a sound giving a variation in pressure of one-thousand-millionth of an atmosphere. The vibrations of the eardrum are passed on to a chain of three bones, called, from their shape, the hammer, anvil, and stirrup, which transmit the movements of the drum, reducing their motion, but magnifying their force, to the inner ear and the ends of the auditory nerve.

As mentioned above, the pressure on both sides of the drum is kept exactly equal by the Eustachian tube, blockage of which by catarrh or otherwise is one of the commonest causes of deafness. This defect may be circumvented by the employment of one or other of the many appliances now on the market, some of which work on the principle that sound is not transmitted by air alone, but may be carried by solids, such as the bones of the skull.

The loudness of sound is bound up with the energy with which the particles of air are vibrating. If they are doing so vigorously, they cause large variations in the pressure on the eardrum, and the sound heard is loud.

The air not only transmits sound, it also, on occasion, can give rise to it. Some years ago, a party of undergraduates were boating in the Thames estuary when suddenly they were scared out of their wits by a fearful shriek in the air above their heads. Next minute they

had even a greater shock, for a shell plumped into the water some distance away and they realised they had unwittingly trespassed on to the Shoeburyness ranges. Fortunately for themselves, they were close enough in for the missile to do them no harm beyond the shock to their nerves caused by the howl of the shock-wave set up by its rapid passage through the air. Any projectile travelling faster than sound gives rise to two compression waves, one at the front and the other at the back, which, in photographs, look very like those made in smooth water by the passage of a ship (Plate XIIb, p. 211). Sounds of this nature are also made during the flight of the large meteors known as fireballs, giving rise to noises that have been compared to the bellowing of oxen, the roaring of a fire in a chimney, the tearing of calico, 'Turkish' music (i.e. that proceeding from the big drum department of the orchestra), etc. These noises are often very loud. The account drawn up, by command of the Emperor Maximilian, of the fall of the meteor of November 7th, 1492, at Ensisheim, in Alsace, states that, at Lucerne, about 80 miles away, the sounds were such that many people thought the houses had fallen down. Again, during the passage over Canada of the famous 'Meteoric Procession' of February 9th, 1913, which consisted of four or five groups of 40 to 60 meteors each, sounds like thunder were heard, and in eight towns houses were shaken.

CHAPTER XI

The Highways of the Air

And I said, Oh that I had wings like a dove !
Then would I fly away and be at rest.

Psalm lv. 6

Man has always desired to fly. When the Psalmist wished for the wings of a dove, he was only expressing what has been one of the dreams that have haunted humanity all down the ages. And there seem to have been those who were not content with dreaming, but who strove to give material expression to their desires.

The traditions of many lands contain what seem to be memories of early attempts at artificial flight. There is the Greek legend of Dædalus. From Rome comes the story of Simon Magus, who tried to prove to Nero that he was a greater miracle-worker than the Apostles Peter and Paul by flying through the air. Geoffrey of Monmouth recounts an early flight over London. According to Geoffrey, the British king Bladud made himself wings by magic, but crashed disastrously on the Temple of Apollo. A particularly quaint story is that narrated by the Persian poet Firdausi, who flourished in the eleventh century. The poem in question tells how an evil spirit persuaded the foolish Shah Kai Kaoos to attempt to fly, and how the Shah made a flying-machine on novel lines. He took a

wooden frame and fixed at each corner a spear with a piece of meat on the blade. To each corner was bound an eagle, and in the centre sat the Shah. When the eagles grew hungry they flapped their wings and tried to reach the meat, and, as they raised themselves, carried the frame and its imperial occupant with them! The story has quite a modern ending, for soon the strength of the birds began to fail, and the Shah made a forced landing in the desert, from which he was rescued with difficulty.

There are also numerous perfectly historical accounts of attempts to fly. Thus, a certain abbot told James IV of Scotland he would fly to Paris. After making wings of eagles' feathers, he launched himself into the air. He escaped with a pair of broken legs. Other experimenters were not so lucky. Neither this venturesome churchman, nor, indeed, anyone else for many years afterwards, realised it was not possible for man to imitate the birds exactly, because he has not the muscular strength to work wings of sufficient size and strength to carry his weight, a fact that was first pointed out by Borelli in 1680. Actual calculation shows that, to raise and support a man of 12 stone, a huge pair of wings 20 feet in span would be required.

Needless to say, the question of flight attracted the versatile mind of Leonardo da Vinci, who actually designed a flying-machine, the wings of which were to be worked by a system of pulleys. Another flying-machine was also designed by Francesco de Lana in 1650, but the first practical step towards using the highways of the air was taken by the Montgolfier brothers in 1783. They conceived the idea of a balloon filled with hot, and therefore light, air, and on November 21st,

1783, the first aerial voyage in history was taken by the Marquis d'Arlandes and Pilatre de Rozier.

Ten days after this first flight, the first hydrogen balloon was sent up by Professor Charles, to whom most of the features of a modern balloon, such as the valve, are due. Free ballooning, largely owing to the impossibility of steering, has never become a practical form of transport, though even to-day there are those who appreciate the sport, as is evidenced by the revival in 1937 of the races for the Gordon Bennett trophy, which were discontinued in 1924 after Belgium had won the trophy outright by winning three races in succession.

The lineal successor of the balloon is the airship. From 1851 onwards various experimenters had toyed with the idea of a navigable balloon, but it was the advent of the internal combustion engine that made the airship a practical proposition, and 1898 saw the experiments of Santos Dumont and Count von Zeppelin and the beginning of the modern airship.

The last decade of the nineteenth century also saw the real coming of the aeroplane. Ever since the days of Leonardo da Vinci and de Lana there had always been those who had dreamed dreams of flight, notably the Yorkshire landowner Sir George Cayley, whose designs were so good that nothing but the absence of a suitable motor prevented their actually flying. Indeed, Sir George is regarded as the real inventor of the aeroplane practically in the form in which it now appears.

Many other flying-machines were planned during the last century, but, as time went on, it was realised that much had to be learned as to the conditions of balance

in the air, and that experiments with gliders were desirable, and Wilbur and Orville Wright began their historic work at Dayton, in Ohio, with these motorless planes, to which they added many improvements, including the elevator for steering the craft in the vertical plane. In 1903 they added a petrol motor which drove a screw, and on December 17th of that year there took place the first controlled flight in a power-driven aeroplane, a machine which is now in the Science Museum at South Kensington.

The following thirty years or so have placed man more or less surely on the highways of the air, but such success as has been obtained has not been won without dust and heat. Long and melancholy is the roll of those who have perished in the cause of progress, and hard and deep has been the thinking and planning called forth by this new means of locomotion. An entire new science, that of aerodynamics, has been called into being to calculate the results of the movement at a great speed of bodies like aeroplanes through the air, for, though it offers little resistance to a man moving through it at a walking pace, it is a different matter when the aeroplane dashes along at hundreds of miles per hour. And calculation and experiment have shown that the ideal shape, the drag on which is almost zero (save for the small amount due to skin friction), is the one that nature has given birds and fishes – the streamline. The modern monoplane is almost of the ideal streamline shape.

The question of the resistance of the air also enters into engine design. When the machine is flying level, the whole power of the engine is used up in overcoming the drag on body and wings as the craft rushes

forward through the air, and as in nearly all aircraft the engines are at the front, the surface presented by these and their accessories, as viewed from the front, has to be kept as small as possible in order to reduce the head resistance.

Another very special problem that has come very much to the front in recent times is the effect of height. Everything else being equal, the pressure developed in the cylinder of an aeroplane engine is in proportion to the weight, and therefore to the density, of the mixture of petrol vapour and air drawn in. Now the atmospheric pressure decreases at the rate of about 1 inch of mercury, or 33 millibars ($\frac{1}{2}$ lb. per square inch), for every 1,000 feet above the ground, while at the same time the temperature falls at a rate which varies from day to day according to the weather, but is usually in the neighbourhood of 3° F. for every 1,000 feet. The result is that the density of the air falls off rather less rapidly with height than the pressure. The matter may be further complicated by the presence of inversions – that is, layers of air in which the temperature, instead of falling with height, actually rises.

Incidentally, this matter of the variation of density with height is not only important to the designer of aeroplane engines, but to the gunner, for shells from modern long-range guns describe such a huge curve that the projectile at the top of its flight reaches a height of several miles. The gun, known as 'Big Bertha,' which bombarded Paris in the spring of 1918 was designed for a range of 75 miles, and sent her 'babies,' as her ton-weight shells were nicknamed, to a height of 25 miles before they descended in a long curve on the French capital. The 'creeping barrage' which

preceded attacking troops, and had the double effect of helping to break down enemy resistance and at the same time of screening the friendly force, also needed great knowledge of upper-air conditions, and it has been said that, through the information they were able to furnish to the artillery, the members of the Army Meteorological Service saved thousands of British lives.

To return to the question of the effect of changing height upon the performance of aeroplane engines. In order to maintain the same power as that developed by the engine at ground level, the inflammable mixture must somehow be delivered to the cylinders at the normal atmospheric pressure of 15 lbs. per square inch at any height. Moreover, to work satisfactorily at great altitudes, the air-screw has to be specially designed, for, unless the pitch of the blades is properly adapted to prevent it happening, the result of delivering ground power to an air-screw in rarefied air would be that the engine would race and finally burst. And that is not the end of the matter, for the braking of the air-screw blades must not be such as would interfere with efficiency. However, the designers and manufacturers of aero engines are very optimistic, and the opinion of one expert is that an engine can be made to go up to a height of 61,000 feet. Indeed, already a special type Bristol air-cooled 'Pegasus' engine, fitted with a specially designed cooling radiator and two-stage blower to increase the air supply to the motor at high levels, has carried Flight-Lieutenant M. J. Adam to a height of nearly 54,000 feet.

Other problems connected with using the highways of the air are those of the general structure of the machine and the proper shape of the wings, which,

ever since the pioneer work of Lillienthal, have been designed with curved surfaces. Another important problem is that which arises out of the limit set by nature to the speed with which the air can move out of the way of the advancing aeroplane, which speed is the same as the velocity of sound, and the nearer the speed of the aeroplane approaches that of sound, the more difficult it becomes to force a path through the air in front. Then, too, there are the effects of the changes in atmospheric pressure on the body of the airman. The invention of pressure suits, such as was worn by Lieutenant Adam, or the use of closed cabins, has, in theory, solvcd the problem of great altitudes. Then, again, very interesting studies have been made, like those carried out in Italy, on the adaptability of different individuals to sudden variations in the surrounding atmosphere. From these investigations it appears that some people adapt themselves easily to rapid changes in atmospheric pressure or of temperature, while others are so affected physically by the changes of the weather that they may be called 'living barometers.' It seems obvious that those belonging to the first class are more likely to make successful airmen than those belonging to the second type, in whom certain parts of the nervous system appear to be over-excitable.

Special problems are presented by airships, the buoyancy of which is greatly influenced by the temperature of the air. For a successful landing, the navigator of an airship must know what temperature he is descending into, and when riding at the mast he must always be ready to trim the craft according to the changing conditions. The reduction of pressure in the upper air

also causes expansion of the gas in the ballonets, which expansion has to be allowed for at the time of filling. It is because of this expansion that the free balloons, used by voyagers into the stratosphere, are only partially filled at the start, and, therefore, appear pear-shaped instead of round.

The air does not offer an uninterrupted highway for balloon, airship, or aeroplane. Wind and weather have the greatest effect upon flying in every possible way. The effective speed of aircraft is much influenced by wind, and it is easy to see that an aeroplane, for example, which does 100 miles an hour in a calm, will do 140 when flying with a 40-mile-an-hour wind and 60 when flying against it. And since all aircraft, however high they may fly during the middle part of their journey, have to begin and end their flight in the turbulent lower layers of the atmosphere, knowledge of the whirls and eddies of the wind near the surface is of vital importance. The Dines anemometer was invented in 1894, but till the demands of the designers of aeroplanes for details of the structure of wind became pressing it was regarded almost as a kind of scientific toy rather than as a serious instrument of research.

The danger to aircraft of all kinds of becoming involved in the turbulent weather connected with the cold front of a depression, with its strong eddying winds and sudden thunderstorms, can readily be appreciated, and it is not too much to say that the constant coming and going along the airlines of the world would be quite impossible without the unremitting labours of the officials of the various meteorological services concerned. Thus, for a year before the successful trial flights of 1937 over the Atlantic air-route, an observer

from the Air Ministry had been travelling backwards and forwards over the proposed route, studying the upper winds and transmitting his results to London for comparison with weather maps prepared from other sources of information.

Mountainous country sets up disturbances in the wind which are of great moment to the airman. Fortunately, clouds are often very good indicators of the presence of anything unusual; thus the existence of a banner cloud is a sure sign of a strong wind at the peak (Plate XIII, p. 242).

Perhaps one of the most dangerous forms of atmospheric disturbance due to mountains is the down-draught in the lee of the peak, the result of encountering which has been most vividly described by that great pioneer of civil aviation in this country, the late Air Vice-Marshal Sir Sefton Brancker.

'A down-blast from the direction of Etna,' he wrote, 'struck us full – and we dropped like a stone for four hundred feet. The engines faded away as the petrol stopped flowing from the tanks; the passengers flew upwards from their seats, clawing the air, suspended for an appreciable space of time: baggage and parcels took to the air within the cabin. Crash! The down-blast ceased as suddenly as it started! The passengers fell back into their seats, the baggage returned to the floor, the engines and we went on our way.'

Sad to relate, it was a down-draught that eventually cost the writer of this racy account his life. Two years later, on October 4th, 1930, Sir Sefton Brancker, then Director of Civil Aviation, sailed from Cardington as one of the official passengers of the State airship R 101. Her 'safe-flying' height was 1,913 feet (length × $2\frac{1}{2}$)

above the ground, but, weighed down with accumulated rainwater, she was only 1,500 feet above sea-level when she approached, from the lee side, the 500-foot high hills near Beauvais. The configuration of the ground affects the wind up to 1,500 feet, and thus R 101 was well within the disturbed area. Caught by the nose in a down-draught, she dipped. There was some free hydrogen inside the envelope, and this rose to the stern, giving it such a lift that, though the elevators were at once put up, the giant airship did not

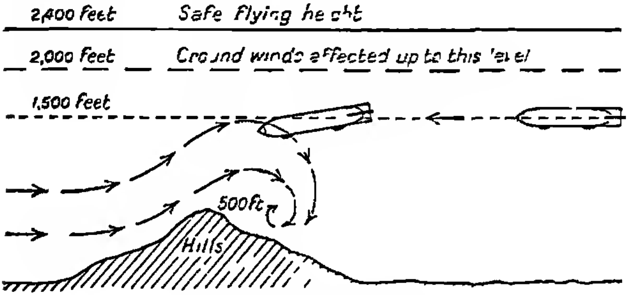


Fig. 21. Loss of R 101

answer, but plunged forward helplessly to her doom (Fig. 21).

Gliders, on the other hand, revel in the currents caused by hills. More recently, too, following the lead given by the late J. Nehring, they have begun to use the ascending currents under cumulus clouds, and when these clouds occur, as they often do, in long rows, the conditions are then so favourable to gliding that such formations have earned the name of 'cloud streets.'

But even in days like these, when almost every week sees another step towards the conquest of the air by man, there are still many who are less thrilled by the

achievements of the mechanical birds of science than by the performances, not only of the birds of the air, but of all other winged creatures that have gained, or attempted to gain, the mastery of the skies.

The attempts at flight are almost as interesting as the successes, and they are found amongst spiders, fishes, reptiles, and mammals.

Perhaps the most successful attempt to fly is that of the gossamer spider, which has attacked the problem in a highly original way. It is a common sight, in the autumn especially, to see numbers of small spiders of various kinds mounting on to some convenient point of vantage, such as gateposts or tall plants. They stand with their heads to the wind and spin out threads of silk from the spinnerets at the end of their bodies. When these threads are long enough to catch the wind, the spiders let go, and sail away on the breeze, often for considerable distances. Should the wind rise, the spiders wind in the threads, and should the wind drop, they pay them out again, just as yachtsmen furl and unfurl the sails of their vessels. When the spiders have come to the end of their journey, they wind in some thread and fall gently to the ground.

The same principle of the parachute is seen at work among reptiles and mammals. The tree-lizard, known appropriately as the flying dragon, which inhabits the forests of the Malay States, has five very elongated and very movable ribs which carry between them a stretched sheet of skin. When the lizard is at rest, these ribs fold in against the body parallel to the spine exactly like a collapsed umbrella, but when it wishes to escape an enemy, or to dive after a swarm of the insects on which it lives, these ribs are extended and

become the framework of a parachute, with the aid of which the lizard can swoop several yards.

Another, but less-known, tree-lizard (ptychozoon) has a long tail bearing a fringe of skin on each side which also helps it to swoop. Again, there is the flying tree-toad which is able to take leaps from branch to branch, and has webs on all four feet, instead of on the hind feet only, as is the case with the common toad.

There are no less than seven tree-dwelling mammals that have developed the parachute, having folds of skin covered with hair extending from the forelegs to the hind legs. The most effective parachute of this sort is that owned by the 'flying lemur,' or colugo, of the Indian Archipelago, in which the fold of skin does not end at the hind legs, but fills the space between them, the tail passing down the middle. Mr. Wallace, the naturalist, once saw one of these creatures glide from one tree to another one 70 yards away, and estimated the amount of descent at 30 or 40 feet, or one in five. This fact led him to the conclusion that the colugo has some power of guiding its movements.

All the creatures mentioned above 'glide' with the aid of natural parachutes, which owe their supporting power to the resistance they offer to the air. Gossamer, too, like feathers, floats, or, rather, sinks very slowly, because it is buoyed up by the air underneath. In a vacuum, where gravity is able to act unhindered, a feather falls as rapidly as a lump of metal.

There has been a good deal of controversy as to whether the famous flying fishes, of which there are two varieties, really fly – that is, whether their fore-fins act as true wings or not. In the case of the common flying fish there is certainly no motion of the pectoral

fins; what it does is to take a great leap out of the water (very often to escape its great enemy, the tunny), using its tail as a propeller and using its fore-fins as vol-planes, and not as wings.

On the other hand, some observers have said they have seen some movement of the fore-fins of the flying gurnard. There also seems to be some connection between the length of the 'flight' and the state of the atmosphere, being short when the air is still and fairly long when there is a breeze.

But at its best the flight of flying fishes and the other creatures mentioned above is only in the nature of an approximation. No less than four times (five, if human efforts be included) in the long history of life upon the earth has the mastery of the air been attained by living things.

Some of the most brilliant exponents of the art of flying among members of the animal creation are to be found among the insects. The wings of insects are really outgrowths from the body-wall, and are composed of two membranes, an upper and a lower, between which are the veins, a strengthening framework of tubes, made of that horny substance, so common in the insect world, known as chitin. These wings are moved by two sets of muscles, the indirect and direct. The indirect, which owe their name to the fact that they are attached, not to the base of the wings, but to the thorax, are the largest in the body, and, with most insects, are the important flight muscles. They consist of two separate groups, the rapid alternate contractions of which raise and lower the wings by their action upon the back wall of the thorax. The direct muscles, on the contrary, though they take their origin

in the thorax, are inserted on the bases of the wings; they aid in steering, and turn the wings backwards and forwards horizontally, the result being that, when in flight, the wings of an insect have rather a curious motion, consisting of a combination of an up and down movement combined with one in a backwards and forwards direction, which makes the path in space taken by the tip of the wing resemble the figure 8. It is in this respect that the wings of an insect, and indeed of all flying creatures, differ from those of an aeroplane. The wings of an aeroplane sustain the craft in the air, and it is propelled forward by the air-screw; the wings of an insect, bat, bird, or pterodactyl act both as propellers and sustainers.

The wings of insects are capable of very rapid motion, and in many species the number of strokes per second is great enough to produce a distinct musical note like the familiar buzz of the bee, which vibrates its wings some 190 times a second. When the insect is tired and the strokes of the wing are reduced in number, the note produced drops about a fifth lower. The house-fly moves its wings 330 times a second, while larger insects, such as dragon-flies and butterflies, only give 28 and 9 strokes per second. These values, however, may be slightly lower than the actual performance of the insect in its free state, for they were obtained by holding the creature gently in forceps so that the tip of the wing brushed against a revolving drum covered with smoked paper, and comparing the record thus obtained with that made in the same way by a tuning-fork of a known frequency of vibration.

The power of flight varies greatly amongst insects. Some, like mosquitoes and house-flies, can only fly for

short distances, while others, like bees and wasps, can make journeys of several miles. Dragon-flies, indeed, have become so much creatures of the air that their legs have become so weak that they are useless for walking, and are only employed for perching and for seizing and holding prey, which the dragon-fly can catch on the wing, a feat in which it is greatly aided by its power of changing direction instantaneously.

The first backboned creatures to fly were the now extinct pterodactyls that lorded it in the air in the far-off days when the chalk of the South Downs was being laid down. Their name was given to them because their bat-like wings were spread out on the enormously elongated little finger. They ranged in size from small creatures about the size of a sparrow to the enormous pteradon, 18 feet across the wings, which is the largest flying animal known ever to have lived, and which, unlike many of its contemporaries, had no tail. As to the flying powers of these veritable 'dragons of the prime' there is some difference of opinion. Some authorities have drawn quite a pathetic picture of the clumsy creatures clambering painfully up some cliff in order to gain a point of vantage from which they could glide or flap awkwardly down upon their prey, and it is quite true that their breastbones only have a slight keel for the attachment of the wing muscles, which, judging from the evidence afforded by the structure of birds, does not indicate great flying ability. On the other hand, as is the case with flying birds of the present day, pterodactyls had the middle part of the backbone solid, so that the wings had a secure fulcrum against which to work, and the frequency with which the remains of pteradon are found in the English and

American chalk (a marine formation) seems to show that these creatures were able to make long excursions out to sea.

Incidentally, a rather successful type of aeroplane has been designed from hints afforded by the pterodactyl.

It is a far cry from the lumbering and probably cold-blooded reptiles that used to flap about where now the South Downs lift their soft curves against the sky and the agile and warm-blooded little mammals that now dart about in the same parts when twilight has fallen. Yet the wing of the bat is on rather similar lines to that of the pterodactyl, only in the case of the bat the membrane stretches across all four long fingers instead of being borne by the little finger alone. From the hand the bat's wing extends to the legs, the knees of which are turned outwards and backwards, in the same way as our elbows, to meet it; it reaches down the leg to the ankles and fills all the space between the hind legs, including all the tail except the tip and leaving the feet free. Many people have a great dislike of bats, and certainly, in the dead animal, the wings are leathery-looking and unpleasant to behold. But, when the owner is alive, the wing of the flittermouse is as wonderful in its way as that of a bird, and it is one of the most exquisitely sensitive structures imaginable. It is well known that a bat will fly round and round a strange room without colliding with anything, and can fly through woods on the darkest night without ever knocking against branches and similar obstructions, for the highly sensitive nerves of the wings seem to be able to feel objects before they touch them.

Like birds, bats are very lightly built, and have a solidifying of the middle of the backbone. Like birds

also, bats have a keel on the breastbone for the attachment of the wing muscles, but in the case of bats it is not very pronounced, and they cannot rise directly from the ground, like very many birds, but have to climb up some object like a wall or a post and drop off into the air. That is the reason why bats sleep upside down, so that, if danger threatens, all they have to do is to let go with their hind feet of the beam or branch to which they are hanging, drop into the air, and fly away without further ado.

As regards flying powers, all bats are very active, but British species, of which there are fifteen, live on insects, and so do not have to travel very far in search of food; but the large fruit-eating bats of the tropics, such as the flying foxes, make long daily journeys, and even cross arms of the sea after their favourite fruits. With the bats as a class, the little ones accompany their mothers as passengers till they are able to fly for themselves, the infant bat clinging on to the fur on its mother's breast so that it does not impede her flight.

But surely the most victorious solution to the problem of flight ever given is that of the birds, which are fitted for an aerial life in many different ways. Their skeletons are lightly built, being, in fact, constructed on the hollow girder principle, so that a comparatively large surface for the insertion of muscles is rendered possible without a prohibitive increase in weight, as would be the case were the bones solid. Most of the vertebræ in the upper part of the spine are fused together in one mass, so as to form a fulcrum for the wings, and there is a well-developed keel on the breastbone for the attachment of the highly developed breast muscles.

Again, the general result of the arrangement of spine, breastbone, ribs, and certain other bones is to form a kind of springy framework against which the wings can work with the best possible efficiency, and which saves the heart from undue pressure during the downstroke of the wings: yet, at the same time, the change in the size of the chest aids the outrush of air in expiration, which, in birds (unlike mammals), is the chief movement of respiration. The lungs themselves, though small and not very distensible, have such greatly branched air-tubes as to present a very large surface over which the blood can circulate to be purified; in addition, they open in a system of air-sacs.

These sacs, which are peculiar to birds, were at one time supposed to give the creature buoyancy, but it has now been shown their real function is to increase the total content of air and economise breathing. They also remove water vapour from the blood, thus helping to regulate the temperature of the body, which, as befits creatures of such exuberant vitality, is high, being 2° to 14° F. above that of mammals. The blood is also adapted to the intense physical life and aerial habits of birds, containing more of the oxygen-carrying red corpuscles per ounce than it does in any other member of the animal kingdom; the corpuscles are also larger than those of mammals. The body is streamlined and covered with a smooth coating of feathers, and the internal organs are so arranged that the heavier ones, such as the liver and gizzard, are below, so that the centre of gravity comes in the right position for efficient flying.

The first use of feathers was possibly that of warmth, but, however that may be, nowadays it is the feathers

that render flight possible for birds. They are arranged on the wing in two series, one, rather widely spaced, running along the bone which corresponds to the forearm, the other, closely packed, along the greatly modified 'hand,' for in the bird the bones of the fore-limbs have suffered great changes. To this framework of bone, which, when the bird is at rest, is folded up into the shape of a letter Z, the flight feathers are fastened by their bases by slender but strong tendons, and they are so arranged as to overlap one another, with the free edges of the quills facing outwards. When the wing is lowered for the downstroke, the feathers come together, forming an impervious sheet, thus preserving the full force of the stroke; but, when the wing is lifted, they open out and allow the air free passage, thus relieving pressure on the rising wing. The nature of the flight feathers varies from bird to bird; the characteristic whirr of the rising pheasant is due to the stiffness and shortness of the quills, whereas the ghostly flight of the owl comes from the fact that, owing to their structure, the wings are literally muffled so that their owner can swoop silently upon the nimble and sharp-eared mice upon which it feeds.

The general nature of the flight of birds is like that of insects, the wings acting as propellers and supporting planes. The speeds attained are variable. Meinertzhagen, who has paced birds from aeroplanes, has found that small song-birds have a speed of 20–37 miles an hour; crows, 31–45; ducks, 44–59; and plovers, 40–51. Migrating birds travel very long distances, and it is thought that the birds usually fly at an average height of 3,000 feet, and travel in stages of about 200 miles

per day. A notable flyer is the Pacific golden plover, which is believed to make an uninterrupted flight of about 2,000 miles from Alaska to Hawaii, and to accomplish the feat on the energy stored in two ounces of body-fat. It has been estimated that, if an aeroplane could travel so economically, fuel costs would be reduced to about one-eighth.

But the form of flight that has captured the imagination of mankind, and which is the reason why the writer of the Book of Proverbs wondered at the 'way of an eagle in the air,' is that known as soaring, in which the bird is able to make use of strong rising currents of air, and ascends majestically without upstrokes in slow, wide spirals to a great height. Unfortunately, this imposing form of flight cannot be often seen in Britain, for the birds that have mastered it are now confined to such comparatively inaccessible districts as the wilder parts of the west country and of the Highlands; but no one who has ever seen a soaring eagle, either in the flesh or through the medium of the cinema, will wonder why this magnificent bird was associated by the Greeks and Romans with Olympian Jove; why, from the days of the Cæsars, it has become the symbol of imperial power; and why the Christian Church paid it perhaps the greatest compliment of all by making it the type of the most inspired of the Evangelists, St. John, who in his Gospel rises to the contemplation of that greatest of themes, the Divine Nature of the Saviour.

Another very remarkable exhibition of flying, that may sometimes be seen in this country, is hovering. Most birds have the power of checking their course and hanging suspended in the air, but the most brilliant

performer in this respect is the kestrel, which hangs motionless, head to wind, wings quivering, and tail spread out and thrust forward, while it scans the ground below. Another remarkable kind of flight is the plunging variety, of which the principal British exponent is the gannet, which dives from a relatively considerable height, at a speed estimated at 100 miles an hour, on to the fish it has sighted in the water below. The force of the plunge taken may be indicated by the results of a particularly despicable trick sometimes played by fishermen, who fasten a herring to a board, which they set adrift. The gannet sees the fish but not the board, and dives as usual, hitting the board with such force as to be instantly killed. Another champion diver is the diving petrel that disappears instantaneously, swims swiftly with its wings under water, and comes out again *in flight*. With such instances before one, there seems every reason to agree with the dictum of a bird-lover that the flight of aeroplanes as compared with that of birds was as prose to poetry.

The birds of the sea are indeed fascinating. There is the great albatross, that soars close to the water, making circles round a ship like a 'perfect skater on a perfect field of ice,' with scarcely a movement of its great white wings. On our wilder coasts the Fulmar Petrel is a common sight (Plate XIV, p. 243). And, nearer home, the seagulls show even Londoners what past masters they are in the art of gliding, sustaining themselves, as they do, in the rising currents of air set up by a cliff, or even the movements of a steamer. It was to these creatures of the air and of the sea that, many years ago, Swinburne addressed words that express to

perfection the joy of those who use the highways of the air:

The lark knows no such rapture,
    Such joy no nightingale,
As sways the songless measure,
Wherein thy wings take pleasure:
Thy love may no man capture,
    Thy pride may no man quail;
The lark knows no such rapture,
    Such joy no nightingale.

CHAPTER XII

Towards the Unknown Regions

'Nothing is difficult to mortals, we seek the sky itself'

HORACE, *Odes I*, ii. 37

There is an old, and rather well-worn, proverb that says that out of Africa there always comes something new. And the same might be said of the atmosphere.

The first attempt to probe into the upper atmosphere was made in 1749 by Alexander Wilson and James Melvill of Glasgow. They raised thermometers into the air by means of a series of kites arranged tandem fashion on one line. The kite, indeed, was for a long time a favourite means for exploring conditions in the upper air, some of the most noteworthy experiments being made in the Arctic during the winter of 1822–3, when Parry and Fisher managed to lift a thermometer some 400 feet from the ground. Later on the box-kite was introduced, and, by using seven kites in series, heights of five miles have been reached. Kites are still employed at certain observatories, but, in inhabited districts, several miles of wire, with only one end made fast, become rather a responsibility. That great pioneer in the exploration of the upper air, M. Teisserenc de Bort, had many anxious moments with his kites. On one occasion, for example, a fallen wire fouled a steamer, and, another day, there were difficulties with a locomotive.

Very soon after the invention of the balloon, its possibilities from a scientific point of view were realised, and in 1784 and 1785 two journeys were made by Dr. John Jeffries, who reported on them to the Royal Society. Some seventy years later the matter was taken up by the British Association, and John Welsh made four ascents from Kew, which were noteworthy for being the first occasions on which an inversion, or layer of air in which the temperature increased with height, was recorded in the free air. Another even more brilliant series was conducted by James Glaisher and Henry Coxwell between 1862 and 1866. These ascents were not without hardship and risk, for in those days such refinements as electrically heated clothing, enclosed gondolas, pressure suits, etc., were unknown, and the aeronauts had to face the rigours of the upper air in an open basket. Thus, on September 5th, 1862, at a height of nearly 29,000 feet, Glaisher fainted, and Coxwell, whose hands were frozen, only just succeeded in pulling the valve cord with his teeth before he too collapsed. Even grimmer was the experience, mentioned in a previous chapter, of Gaston Tissandier, who woke from his swoon to find his two companions dead; indeed, this tragedy stopped scientific ballooning for the time being. But it was revived by the Aeronautical Society of Berlin, which, by 1900, had published three volumes of records, and under whose auspices was made the ascent that till modern times held the record for altitude. On July 31st, 1901, Drs. Berson and Süring reached a height of 34,500 feet. It is possible that this figure is an underestimate, but, while the balloon was at its highest altitude, both occupants, despite the fact that they were breathing oxygen, were

unconscious. And, in 1927, an American, Captain Gray, who reached the height of $8\frac{1}{2}$ miles, paid for his record with his life.

As is well known, during the past seven years balloon ascents have been made far into the stratosphere, following the lead of Professor Auguste Piccard, who, with his assistant, M. Kipfer, ascended on May 27th, 1931, in a balloon of a new type, in which the basket was replaced by a closed cabin of aluminium, and gained the height of 9·95 miles. Another ascent in 1932 carried him to $10\frac{1}{2}$ miles; the gondola used on this occasion may be seen in the Science Museum at South Kensington, to which it was presented by the Belgian organisation that supported Professor Piccard financially. Since 1932 seven other ascents have been made in the U.S.A. and Russia, the last and most successful being that of *Explorer II* on November 11th, 1935, when a height of well over 13 miles was reached and most valuable scientific results obtained; for all these flights are not 'stunts,' but serious endeavours to probe into the secrets of the upper air. At the present time efforts are being made to construct a balloon that will go still higher. Professor Piccard's brother is experimenting with a gondola which is raised, not by one large gasbag, but by a fleet of smaller ones, and the experts of the U.S. Bureau of Standards believe it is possible to build a balloon which could carry two men and a certain amount of apparatus to 18 miles.

But such penetration of the stratosphere has its limitations, and the main source of information as to what is going on above our heads comes from the sounding balloon, which was first introduced in 1892 by MM. Hermite and Besançon, to offset the inevitable risks

attendant upon the exploration of the upper air by manned balloons. The sounding balloon is now used all over the world, and, though the actual type varies from country to country, the main design is the same. It is a small balloon, made of thin rubber and inflated with hydrogen, which carries a light frame to which is attached the meteorograph. The type used in British practice only weighs about 2 oz., and consists of a very small aneroid barometer and metallic thermometer, which scratch marks on a metal plate the size of a postage stamp. When the balloon has reached a certain height it bursts, and the frame and meteorograph fall to the ground to await discovery. A label attached to the frame requests the finder to notify the Meteorological Office, and promises a reward. A recent refinement of this method is the 'radio-sonde,' in which the instruments are so connected to a small radio set that their movements cause the transmission of characteristic signals, which are received at the ground station. This method is especially valuable in sparsely populated districts where there is always risk of the meteorographs being lost. For instance, most of the balloons sent up in December 1908 in the Punjab were carried by strong upper winds towards Tibet and lost, though it was learned later that one so frightened the natives that the Buddhist monks offered prayers for months to propitiate the strange visitor from the skies.

It was these sounding balloons that first brought the existence of the stratosphere to light. The early explorations of the upper air showed that the temperature, on an average, fell roughly 3° F. for every 1,000 feet of altitude, the reason for this being (very briefly) that, owing to air being very transparent to radiation

from the sun, it transmits more than it absorbs, so it is heated mainly in the lower layers by contact with the warm surface of the earth. Then, at ordinary temperatures, it gives out more radiation than it absorbs. Up to 1899 it was believed that this state of things continued indefinitely, but in that year Teisserenc de Bort found himself obtaining records that either indicated that his apparatus was faulty, or else that, at a certain height, the temperature ceased to fall. Other investigators took up the matter, and soon the existence of the stratosphere was placed beyond all doubt.

The boundary between the stratosphere and the lower atmosphere, which has received the name of the troposphere, is called the tropopause, which seems to be lower over the poles than over the equator, where it reaches the height of above 11 miles. As the temperature of the air keeps on falling till the tropopause is reached, the stratosphere is actually warmer over the poles than over the tropics; indeed, the lowest temperature ever measured – minus 131° F. – was recorded in the stratosphere over that particularly sweltering neighbourhood, Batavia. Over these islands the average height of the tropopause is about seven miles. Near the tropopause there are often very strong winds, but above it the air-currents are quite moderate. From day to day variations take place in its height.

As regards the stratosphere, it is, in many respects, the complete opposite of the troposphere. The old Stoics were quite right when they allotted mists, rain, clouds, and such-like to the lower portion of the atmosphere; the stratosphere is untroubled by such happenings, though occasionally clouds of the beautiful iridescent type studied by Professor Störmer do form.

Indeed, Stormer regards them as common features of those parts of depressions where the air is ascending; that they are not more frequently seen is accounted for by their often being covered by lower clouds. Be that as it may, it is well known that both depressions and anticyclones extend far up into the stratosphere; indeed, many scientists look to the stratosphere as the source of pressure changes on the surface.

Another question that has been much canvassed is the reason for the even temperature of the stratosphere. Probably the most acceptable one is that it arises from the nearly exact balance between absorption and radiation. The matter is complicated by the fact that many records from sounding balloons, sent up in various parts of the world, show an increase of temperature with height. There are also other questions arising from the differences in temperature, but these would lead us into rather deep waters. It must be said, though, that it is believed that these differences of temperature are one of the powers behind, not the throne, but the manifold and somewhat perplexing activities of the Clerk of the Weather.

But, though there is still much to be learned about conditions above our heads, enough is known for there to be a regularly published Upper Air Section to the *Daily Weather Report*, and for an original type of weather map for airmen to be designed. This map takes the form of a box, on the bottom of which is depicted the weather conditions at the surface, and is fitted with a series of glass shelves on which is shown the state of things at different levels in the air.

Not all sounding balloons are sent up merely to record such prosaic matters as temperature, or to

minister to the needs of what has been termed 'bread-and-butter' meteorology. At Kew Observatory a series of ascents have been made with sounding balloons fitted with special apparatus designed to collect samples of air from well within the stratosphere, and these samples, on being analysed by Drs. Paneth and Glückauf of the Royal College of Science, have shown that there are slight but definite changes in the composition of the atmosphere at heights of between 12½ and 17 miles, in the shape of an increase in the amount of helium, and a decrease in the amount of oxygen.

Again, balloons have played their part in the investigation of those mysterious radiations from outside space known as the cosmic rays. It was in 1900 that it was proved that air was not a perfect insulator, but that the leaves of a charged electroscope, however perfectly insulated, would very, very slowly collapse, thus showing that there was a leak of electricity. It was also soon discovered that the rate of this leak of electricity could be greatly diminished by shielding the electroscope on all sides by a cover many inches thick of some heavy material such as lead. This result was at first interpreted as due to the shielding of the electroscope from the rays from the radio-active substances, present in minute amounts, in the ground and surrounding buildings, and, to test this theory, the instruments were taken up in balloons; but, to the surprise of the experimenters, this ionisation effect, as it is called, was much greater. Preliminary investigations were carried out between 1911 and 1913, but some of the most brilliant work on this fascinating subject has been carried out quite recently by Professor Regener, who in 1932 sent up a self-recording instrument to a height

of no less than $17\frac{1}{2}$ miles, which instrument made photographic records at intervals of four minutes. He also sunk a similar instrument to a depth of 700 feet below the surface of Lake Constance, where he found the ionisation, or power of the air to conduct electricity, to decrease continuously to that depth, though, even there, some effect was apparent.

Professor Piccard's object in making his stratosphere ascent was mainly to investigate these cosmic rays. His instrument was connected with an amplifier, so that, when he had ascended well beyond the tropopause, and had left a good three-quarters, if not more, of the atmosphere below him, he could hear, as he remarked in his report, the cosmic rays 'rattling down on his gondola.'

During the last few years a great deal of research has been undertaken into the nature of these mysterious radiations, the sum total of which has been to show that, day and night, there is coming down through the atmosphere a torrent of radiation powerful enough to penetrate at least 700 feet of water. The atmosphere itself has an absorbing power equal to that of 33 feet of water. The amount of radiation that gets through to a particular place is markedly affected by the changes of the barometer, owing to the greater or less quantity of air overhead as pressure rises or falls; but, when this is allowed for, it is very constant in time. Measurements, which were carried out all over the world by Professor A. H. Compton and a band of helpers, also show that the intensity of the radiation varies from place to place, being greatest at the magnetic poles and least at the magnetic equator, results which prove that some part at least of the rays consists

of particles charged with positive electricity which are attracted towards, the magnetic poles.

The rays vary greatly in hardness or penetrating power, some being capable of passing through many yards of lead. Sir James Jeans suggests that this is due to the fact that the original cosmic rays, by the time they reach earth, are accompanied by a mixture of particles and waves of various kinds, which are the debris of molecules shattered by the radiation on its way through the atmosphere. For, as Jeans points out, the one great outstanding property of the cosmic rays is their power to break up molecules and even atoms on which they fall. That is why they break down the insulating power of air. The atom, in its complete state with positively charged nucleus and rings of satellite negative electrons, is neutral, but if, through the impact of cosmic rays, or any other reason, it loses one or more of its negative charges, it becomes a charged atom or ion. The cosmic rays are estimated to break up ten atoms in every cubic inch of air every second. They must also, as mentioned by Jeans, smash atoms by the thousand, in the bodies of ourselves and other living things, though no doubt, of course, life on this earth is so adapted to the conditions that it comes to no harm. If the American engineers carry out their plans and construct a manned balloon capable of rising to 18 miles, they surely (so some think) must bear these rays in mind, and what would be the effect of even a short exposure to the incoming torrent of hard radiation from space, since at such a height 98 per cent of the protective blanket of air is left behind, which, tenuous as it seems to be, has a screening power equal to a foot of lead.

Where do these rays come from? The question resolves itself into finding a source of energy great enough to account for their extraordinary hardness, for to produce rays that can go through 700 feet of water requires voltages running into the thousand million. Some authorities are inclined to regard thunderstorms as the fountainhead, but most authorities look for its origin in inter-stellar space. Millikan and Cameron believe that the rays come from the actual building up, out of its ultimate constituents of positive and negative particles, of matter, with the resulting conversion of mass into energy. But, though this theory may account for the 'softer' or less deeply penetrating rays, it does not account for the very hard rays, which are believed by Jeans, Regener, and others to be the result of the actual annihilation of matter, positive and negative particles coming together and passing out in a flash of energy. At any rate, whatever the ultimate source of these rays may be, their total energy is enormous, being estimated by the Abbé Lemaître as being equal to one-thousandth of the power locked up in all the matter of the universe.

But interesting and important as they are in the scheme of things, the cosmic rays do not give us as much help in exploring the otherwise unknown regions of the atmosphere as do other visitors from outside space.

Cosmic rays are not the only form of bombardment from outer space against which our atmosphere forms a sure shield. The space between the worlds seems full of fragments of rock and metal, originating perhaps from disintegrating comets, or, maybe, an exploded planet, which fragments, when the earth

passes by, succumb to her attraction, and would, but for the air, pour down upon her surface in a bombardment, compared with which even modern shell-fire would be nothing. For, though the average meteor is quite small, it travels at speeds ranging from 10 to 60 miles a second. But, on entering the atmosphere, not only is the meteor slowed down by the resistance of the air, but by the time it has reached within about 80 miles of the ground the air in front of it is so heated by compression that a cap of hot air is formed. This cap communicates heat to the outer layers of the meteor, which are vaporised and become incandescent, with results described elegantly by Dante in the lines:

> . . . along the still and pure serene
> At nightfall glides a sudden trail of fire,
> Attracting with involuntary heed
> The eye to follow it, erewhile it rest
> And seems some star that shifted place in heaven.

Usually the meteor is completely dissipated by the time it reaches the 50-mile level; some, however, manage to get below 30 miles, and a very few (one in twenty million) reach the surface of the earth. Some of these have their speed so checked by the resistance of the air that they have been known to strike the surface of a frozen lake without breaking it; others, however, retain enough energy of motion to bury themselves in the ground. The $22\frac{3}{4}$ lb. Strathmore meteorite fell through the roof of a house. In the case of really big and swift meteors the air cannot do much. These carry the cap of hot air down to the ground, and this, and the heat developed when the fall is checked by sudden contact with the ground, produce very sensational results. The effects produced by the great Siberian

meteor of 1908 have already been mentioned, and in 1932 Mr. H. St. J. Philby found traces of another fall in the Arabian Desert, at a site identified in Arab legend as that of a wicked city destroyed by fire from heaven. In this case the heat developed by the impact was so great that the sand was melted (quartz melts at 2,912° F.). Quantities of liquid silica seem to have spurted out through an atmosphere of melted iron and silica with the formation of thousands of what Mr. Philby's Arab companions insisted in regarding as the fire-blackened pearls that once adorned the ladies of the harem. Indeed, large numbers were taken to Mecca, where they went the round of the bazaars 'with disappointment in their train.'

But, even though a meteor reaches earth, it is usually much the worse for wear, being greatly reduced in size, and frequently rent in pieces by the centrifugal force set up by the spin caused by air pressure acting on an irregular surface. Meteorites are covered with a brownish glaze, the result of high temperature, and are often pitted all over with 'thumb marks' similar to those found on grains of gunpowder blown out during the firing of a big gun.

For many years meteors interested astronomers only, but when meteorologists began to justify their name (meteorology = the science of things up above) and take an interest in the upper air, they soon realised that meteors could afford much interesting and otherwise unobtainable information. Large meteors often leave a luminous train behind them which persists for some time, and the drift of which gives some idea of the speed and direction of currents of air. For instance, the train left by a bright meteor, that appeared early

in 1937, showed that, at the 60-mile level, there was a wind of 133 miles an hour.

The suddenness of the appearance of a fireball rather interferes with exact observation, especially in the case of an amateur, but observations of the drift of the train can be carried out at leisure. A convenient way of noticing its movement is by using neighbouring stars as points of reference.

Now, after the stratosphere was first discovered, it was thought the conditions found therein of cold and fairly uniform temperature would persist indefinitely upwards till the atmosphere thinned out altogether. The present picture is very different (Fig. 22). About 1922, Drs. Lindemann and Dobson of Oxford made an inquiry into the behaviour of meteors, and found that their luminosity, at the heights at which they appeared, could only be accounted for by assuming that the temperature of the upper layers of air must be very high – in the neighbourhood of 81° F., in fact. At first such startling results were received with a good deal of scepticism, but confirmation has come from many sources, the principal being the studies of Dr. Whipple and others on zones of silence and unusual audibility, facts which can be perfectly explained by assuming the existence of a warm layer of air immediately above the stratosphere, a region which is now limited, by many meteorologists, to that bounded above by the 20-mile level.

The warm, sound-reflecting layer, which has an approximate thickness of about 30 miles, has been called the ozonosphere, because it seems to contain most of the ozone in the atmosphere. It is to the ozone that this region very likely owes its high temperature, for

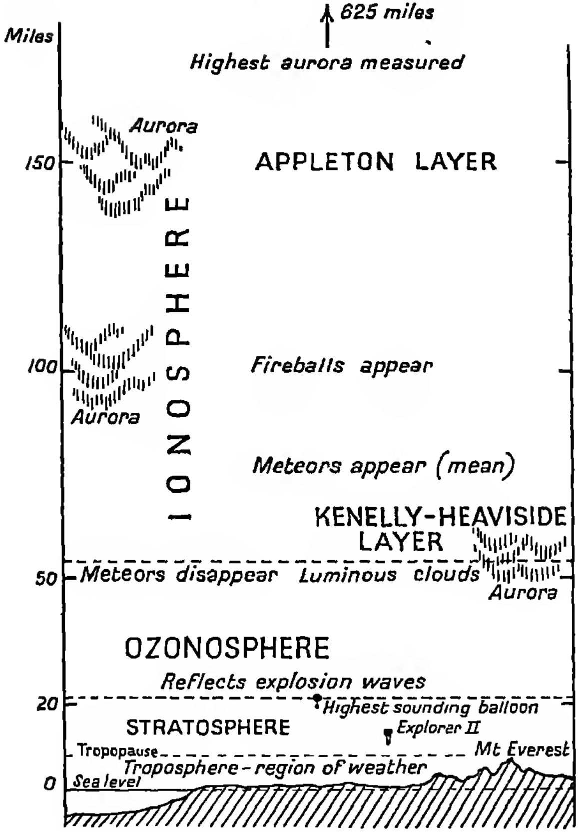


Fig. 22. Structure of the atmosphere

the general view at present is that the very short and powerful ultra-violet rays from the sun act upon the oxygen and turn it into ozone, and, as ozone absorbs a good deal of radiation and gives out very little, it would become rather warm. The whole matter is still being

discussed, but it is stated that three French scientists have developed a new and promising method of attack on the problem which, however, is too technical to be described here. Be that as it may, there can be no doubt that the absorption of the extreme ultra-violet rays by ozone is very thorough, and it is significant that those rays which are cut off are those which seem most harmful to life.

Even those ultra-violet rays that are allowed to pass the ozone, necessary as they are to life, are harmful in excess, as incautious sun-bathers and mountaineers know to their cost, for it is the ultra-violet rays that cause sunburn and snow-blindness. If, by some mischance, the ozone disappeared for a space and the rays of a wave-length shorter than about 3000 A.U.[1] (i.e. Angström Units, for the extreme smallness of the wave-lengths of light makes a special unit more convenient than the usual standards of length) got through, the results to humanity would be disastrous indeed. It is because of these active and dangerous rays that workers with the electric arc have to have their eyes protected by special goggles.

Above the ozonosphere, from about the 50-mile level to an indefinite height stretches that region of the atmosphere now called the ionosphere, which has received its name from the ionised or conducting layers that play such an important part in the transmission of radio. In the early days of radio it was believed that it would be impossible to send messages over long distances – say from Europe to America – because the waves would be stopped by the curvature of the earth. So when Marconi received signals from Newfoundland great

[1] A.U. = 1/10,000,000 millimetre.

surprise was caused. That was in 1901, and in the following year Kennelly and Heaviside suggested that there might be a conducting layer high up in the atmosphere from which the radio waves would be reflected back to earth. But it was not till 1925 that Appleton and Barnett succeeded in measuring its height, by recording the original signal and its 'echo' on a moving film. The distance between the two gives an idea of the height from which the signal has been returned. From such measurements they found that the height of the Kennelly-Heaviside or E layer is about 60 miles. Later observations showed that it owes its conducting powers to ultra-violet light from the sun, and is chiefly concerned with the reflection of long waves.

On the same films as were being used to record echoes from the Heaviside layer, Professor Appleton found other marks which indicated that the signals were also being returned from another reflecting layer at a height of roughly 150 miles, which has been given the name of the Appleton or F layer. This layer reflects short waves. During the last two years or so it has been shown that the Appleton layer really consists of two divisions – the F_2 layer, which is about 150 miles high, and in which the ionisation or number of conducting particles in a given space is very high; and the F_1 layer, which appears in the daytime only about 40 miles under the F_2 layer. This lower layer is caused by ultra-violet radiation from the sun, but the F_2 layer according to Appleton, seems to be connected with high temperatures in the upper air, temperatures which, he believes, reach in summer the astounding level of 1,600° F. The Heaviside layer is similarly complicated in structure and in behaviour.

Indeed, as research proceeds the more complicated does the ionic structure of the atmosphere become. Recent investigations have shown that not only is there a G layer above the Appleton layer, but that below the Heaviside layer are the D layer, at an average height of $37\frac{1}{2}$ miles, and two others at heights of $12\frac{1}{2}$ and $7\frac{1}{2}$ miles respectively. This latter may, however, really consist of scattered clouds of ions.

Moreover, investigation has shown that the power of the atmosphere to transmit radio is much affected by the weather. More than 30 years ago Captain (afterwards Admiral Sir) Henry Jackson, when conducting experiments in the Mediterranean, noted a marked connection between the weather conditions and the strength of signals. On one occasion two of H.M. ships, whose sea-signalling distance was 65 miles, could not hear each other when they had drawn apart only 22 miles. It was observed at the time that, though the weather was fine, the barometer was falling. More recent investigations in the United States have shown that the height of the D layer is much affected by changes in atmospheric pressure, being 10 times as great when pressure is low as when the reverse is the case.

Another interesting effect of weather conditions on radio transmission is shown below. The diagram gives the result of the presence of a surface of discontinuity or boundary between air masses of different temperature and humidity. The strength of signals received at Strelitz-Alt from sending stations lying outside the boundary of the discontinuity is much diminished, whereas that from the particular transmitter covered by the discontinuity is greatly enhanced (Fig. 23).

Moreover, the ionosphere is inevitably exposed to many disturbing influences. For instance, a very powerful radio transmitter may affect the ionosphere so

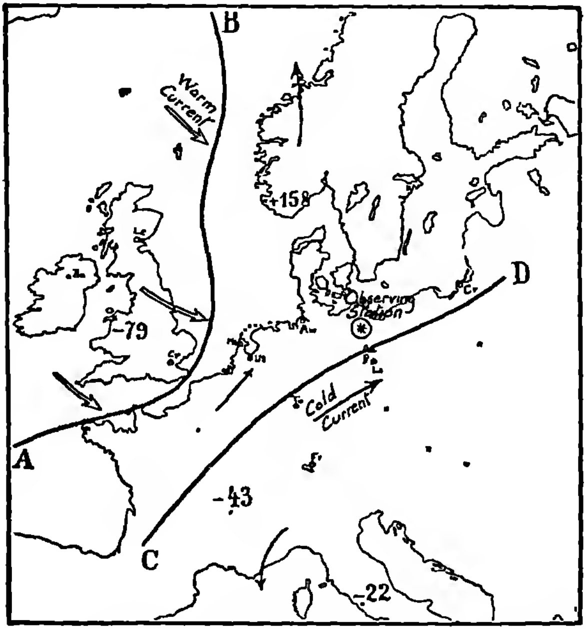


Fig. 23. Effect on signals of discontinuity or boundary between air masses of different natures. The numbers show the percentage increase or decrease in the intensity of reception at the observing station of the signals from the stations covered with the figures. (*Q.J.R. Meteor. Soc.*, 1929)

strongly that it not only varies in sympathy with the modulations, or changes in intensity, of the broadcasting station, but imposes them upon any other waves that happen to be reflected at the time. That is the cause

of the unwanted snatches of music or talk that sometimes break in upon a broadcast programme.

Then, the ionisation of the upper air is largely controlled by radiation from the sun, and it therefore reflects faithfully the various perturbations of that luminary. Now, the power of the several reflecting layers to send back radio waves depends upon the number of ions in a given space, and the shorter the wave-length the more ions there are needed for reflection. Indeed, ultra-short waves (below 10 metres) seem to be able to escape through all the layers out into space: one of the technical difficulties of television transmission. For adequate reflection the waves of the broadcast band require a concentration of 100,000 ions per cubic centimetre. At night-time this concentration exists, but, with the coming of day, the ions recombine and the concentration falls; hence the well-known difficulty in picking up many foreign medium-wave broadcasts during the day.

The number of ions is also controlled by the amount of electro-magnetic radiation from the sun. When sun-spots, which are the outward and visible sign of solar activity, are numerous, the radiation from the sun increases and more ions are produced, so that the reflection of long radio waves is improved, but that of short waves diminished owing to the increased absorbing power of the regions traversed by these waves.

The short-wave band is very sensitive to solar conditions. Many poets have praised the faithfulness of the flower that always turns to the sun, but the fidelity of the heliotrope is as nothing to that of the radio waves. When the sun is observed or photographed by the light of the red spectral line of hydrogen (details will be

found in all books on astronomy), the spots are often seen to be surrounded by whirls of this gas. Also, too, sudden eruptions of bright hydrogen are sometimes observed, eruptions that frequently coincide with sudden fade-outs on the short-wave band. The use of short-wave transmission in commerce has meant that these disturbances are of more than purely scientific interest, and research is being actively pursued, notably at the Commonwealth Solar Observatory at Canberra, where it has been found that, in many cases, the ordinary D region ionisation is more than doubled during one of these hydrogen eruptions, even though no more than $\frac{1}{2000}$ of the total area of the solar surface is involved. It is believed that these disturbances in the ionosphere are due to intense emission from the eruptive area of the Lyman ultra-violet line of hydrogen at 1215.6 A.U.

Even some of the humblest members of the sun's retinue seem to be able to disturb the ionosphere. Disturbances of this region have been noticed in November, about the time when the earth crosses the orbit of the Leonid meteors, disturbances which, it is thought, are due to the sudden injection into the atmosphere of quantities of dust.

There is some support for this latter idea. It has been noticed that, on dates which coincide with the passage of the earth across the orbits of certain comets, curious streaks of luminous haze have been seen in the night sky. And, whether or not these streaks do come from the debris with which the orbits of comets are presumably strewed, there can be little doubt that some of the more intimate encounters between this planet and comets have left traces behind them. On June

26th, 1861, when the earth spent two hours traversing the tail of a comet; the sky was overcast with a peculiar glow, and a country rector, who always made a point of reading his evening sermon by daylight, had to use a couple of candles. Again, on May 18th, 1910, when it seemed likely that the earth would pass through some portion of the 20-million-mile-long train then sported by Halley's Comet, careful watch was kept on the sky. At many places nothing unusual was seen, but at others observers obtained what they considered to be proof that our planet was immersed for some time in the debris from the comet's train. Thus, in Germany, on May 19th, both the sun and moon were seen to be surrounded by the very large corona, known as Bishop's Ring, which is due to very fine dust in the upper atmosphere. Again, on the same day the twilight was noted to be of an 'entirely unexpected intensity, dimension, and duration. Three purple lights, following one after the other, could be observed.' During the next twelve months many reports were made of strips and masses of luminous haze in the sky.

The whole question of these strips of luminous haze, the position of which in the sky shows that they are quite distinct from the aurora or the Milky Way, is a very interesting one, and has been mentioned in the 1937 Report of the Aurora and Zodiacal Light Section of the British Astronomical Association. It is a matter that amateurs, living in the country away from the glare of town lights, might well take up.

Quite distinct from these odd patches of luminous haze are the silvery clouds which appear in summer, and which, according to Störmer's measurements, are 50 miles high. The nature of the matter which

composes them is still the subject of controversy, some authorities suggesting ice-crystals, and others dust from inter-planetary space. One of the most remarkable things about these clouds is their height, which is always at the 50-mile level. It is rather significant that the part of a meteor's flight which gives long enduring trains also is between 50 and 60 miles up. It really seems as if there is some significance about these figures.

But however interesting these particular tenants of the upper atmosphere may be, they cannot vie in beauty and fascination with that mysterious manifestation of electric force, the streamers and draperies of which, had they decked the night skies of more favoured lands than those which encircle the poles, would surely have rivalled the rainbow in the affection of nature-lover and artist alike.

The earth is a great magnet surrounded with an atmosphere. The sun is a super-power station sending out, with an intensity that waxes and wanes somewhat irregularly through a period of eleven years, streams of electrified particles which, as they approach this planet, are captured by its magnetic field, and spiral round the lines of force till they collide with the molecules of gas in the very rarefied upper layers of the atmosphere above the polar regions, and cause them to glow. Professor Nordenskiold had it that the incessant encounters between these high-speed charged particles and the molecules of air resulted in the earth being encircled at the poles by two perpetual girdles of light. Be that as it may, there is a definite zone in both hemispheres in which displays are most frequently seen. These zones, owing to the fact that the magnetic and geographical axes of the earth do not correspond, are

irregularly placed; in the northern hemisphere the polar Light Girdle reaches as far south as 50° N. in Canada, but only touches the Arctic Circle this side of the Atlantic. Thus, in Europe, often the only thing that can be seen of a display is a glow like dawn on the horizon, for which reason Gassendi, in 1621, proposed the name which has gained international currency – aurora. Other names are the 'polar lights' and 'northern lights.'

It is difficult in cold print to do full justice to the beauty of a really fine aurora. It must suffice to say, then, that a display usually begins as an arch of greenish light, which in time may erupt, as it were, into that multitude of moving streamers that gave the aurora its Gaelic name of *Na Fir Chlis*, or the Nimble Men, and which made the old Norse skalds think of the Valkyries riding the heavens. And the men of the Hebrides told of the clansmen of elfland fighting the 'Everlasting Battle' for the love of a lady. Sometimes the rays extend rapidly sideways, so that the sky seems full of curtains of light. Sometimes, too, in very active displays, there are explosive bursts of vividly coloured light (flaming aurora), or strong waves of light move rapidly upwards like 'surf breaking on a beach.'

Professor F. J. M. Stratton has pointed out how the ray and curtain forms of aurora are the natural result of the penetration of the earth's atmosphere by ionised clouds of gas along paths governed, at least in part, by the earth's magnetism, and Carl Störmer of Oslo has also worked out in detail the paths of electrons corresponding to particular kinds of aurora.

The researches of Professor G. E. Hale at Mount Wilson have shown that sun-spots are often surrounded

by hydrogen vortices (Plate XV), and it is believed that the inward motion of charged particles along these whirls sets up the strong magnetic field found in these spots. The close link between short-wave radio disturbances and solar activity has already been mentioned; there is as close a bond between the sun and the aurora. When solar activity is feeble, as has been the case of recent years, displays are comparatively few; when the activity increases, as it seems to be doing now, displays become commoner and more spectacular. The year 1937 saw a great revival of activity. In the early part of the year there was a series of three displays which began on January 7th and was repeated at intervals corresponding roughly to the intervals at which the disturbed solar area was brought round opposite the earth by the rotation of the sun. At the second return, early in February, the spot group was visible to the naked eye, and was associated not only with an aurora but with an annoying fade-out during the broadcast commentary on the Australian Test-Match. Another very spectacular display took place at the end of April, and was connected with the greatest magnetic disturbance recorded at Stonyhurst since 1929.

Scarcely had these words been written when on January 25th, 1938, all Europe was thrilled by one of the finest displays for many years. As seen from Hastings (Plate XVI, p. 281) the double arch (a rare phenomenon in Southern England) was greenish in hue, while the crowns of light, covering the Plough and the upper part of Cygnus, were crimson shot with orange. The bright star just above the arch is Vega, while the Pole Star is to the right top centre. This aurora was

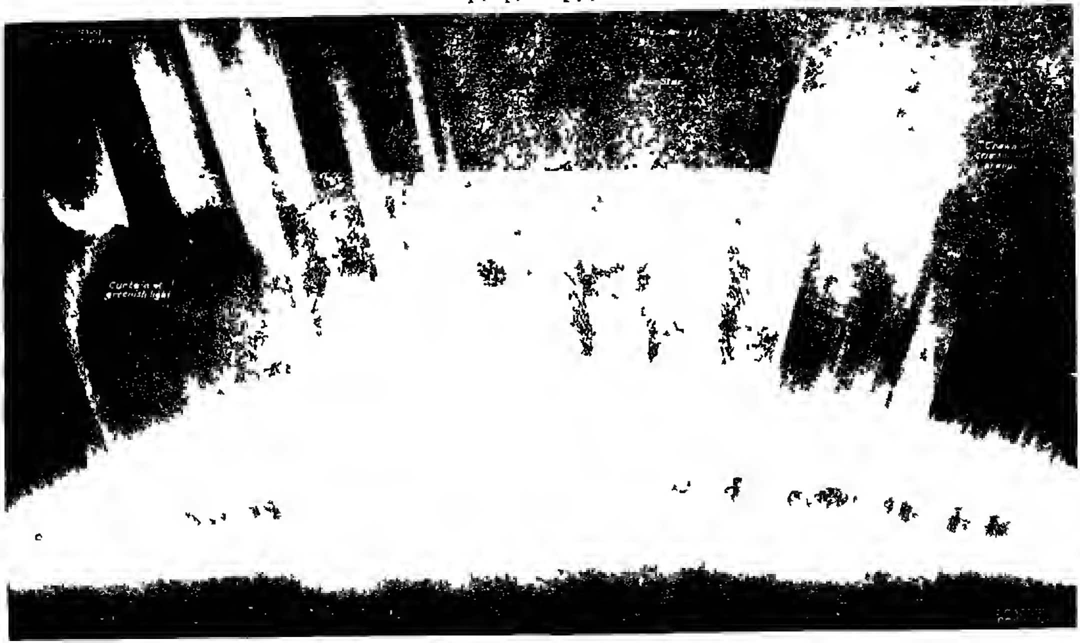
PLATE XV

Hydrogen Whirls in the Sun, August 30, 1924

Photographed in the light of the red line ($H\alpha$) of hydrogen at Mount Wilson, California

By courtesy of the late Professor G. E. Hale and the 'Encyclopædia Britannica'

PLATE XXI



The Great Aurora of January ... 1938 as seen from Hastings (Lat. ... N ...) ... 7 p.m. (p. ...). This display was characterised by rapid changes, variety of forms, long duration, brilliant colour and great elevation ...

accompanied by the most violent magnetic storm at Greenwich since 1909 and by disorganisation of the Post Office short-wave radio-telephone circuits to America. For some days previously there had been a very large spot on the sun, but that had just passed off the visible disk.

Should there be a very great disturbance on the sun, then the earth literally thrills from pole to pole, and aurora streamers not only adorn the heavens at the poles, but deck tropic skies as well. Such was the case on February 4th, 1872, when displays were seen at Mauritius and Tobago, and on September 25th, 1909, when an aurora was seen at Singapore, only one degree from the equator !

One of the minor mysteries of the aurora is that though, to many people, the displays take place in ghostly silence, there are others who stoutly maintain that they hear sounds like the swishing of silk or the whistling of the wind. Though it is impossible to doubt the sincerity of many of these witnesses, it does not seem likely that sounds produced in such highly rarefied air as that at least 50 miles up could reach the ground, for even detonating meteors have to be fairly low to be heard. Some authorities, therefore, think that the sounds heard come really from the tinkling of the breath as its moisture condenses, as it does at zero temperatures into myriads of tiny crystals, or from the common complaint of 'noises in the head.' Others, like Professor A. S. Eve, think the sounds come from small 'brush discharges' of electricity such as occur from snow or bushes in dry cold weather, and Sir George Simpson believes that the imagination probably had a good deal to do with the matter, pointing out that the waving

motion of the draperies is so real that the idea of the rustling or swishing of silk would follow automatically. Incidentally, this view is supported by the fact that some people declare the noises occur *simultaneously* with the motions of the aurora, whereas, if the sounds were real, one would expect a considerable lag between sight and sound.

The chief reason for doubting, however, that sounds from the aurora can be heard is the height above the ground at which the displays take place. Despite the claims of many observers, who have asserted in good faith that they have seen the aurora against distant hills or just above the tree-tops, it is more than likely, as Sir George Simpson has pointed out, that such persons have been deceived by moonlit mists, which look very like auroral beams, and also by the fact that, as the aurora appears simply as patches of light in the sky, it affords no means by which its distance can be judged. It is related that astonished beholders of a brilliant meteor at a presumed height of 50 miles sallied out of their houses the next day to make sure that the chimneys were intact.

For the past thirty years or so, Professor Störmer has been engaged in measuring the height of the aurora. He is helped by a team of observers, scattered over Norway, who are in telegraphic communication with each other. Simultaneous photographs are taken of the aurora from different places, and, from the different positions of the arcs and draperies in relation to the background of stars in the several pictures, the height and exact position in space of the display can be calculated. Thus, a very beautiful curtain aurora, which was photographed simultaneously from two towns 102

miles apart, was found to be hovering over the neighbourhood of the Orkney Islands at a height of about 50 miles.

As the result of hundreds of such observations, Störmer has discovered that there are two distinct levels in the atmosphere at which the aurora occurs – namely, that between 50 and 200 miles, and that between 350 and 630 miles. This latter region is so high that, even at night, it is in full sunlight. The discovery of this upper region was made in 1926 and was the first hint that the atmosphere extended to such high levels.

The aurora has not only revealed that the atmosphere is very high; it has also given us hints as to what is its composition. Now, about thirty years ago, it was generally thought that in the upper reaches of the atmosphere, where there is no mixing of gases because of the absence of turbulence, the various constituents would sort themselves out according to their weight. The uppermost layers, therefore, so it was believed, would consist of light gases such as hydrogen and helium, and some scientists also thought there might be an unknown gas, which was provisionally labelled geocoronium. This idea of a mysterious unknown body in the air was probably strengthened by the fact that examination of the light from the aurora by the spectroscope showed that the aurora not only emitted a series of bright bands, due to molecules of nitrogen, but that it also gave out a very prominent green emission line at 5577 A.U. And, in 1901, it was found that this line also appeared in the spectrum of the soft green light that is given out by the clear night sky, under all conditions and in all latitudes.

At one time it was thought that the substance responsible for 5577 was the rare gas krypton in the spectrum, of which there is a conspicuous green line. But accurate measurements showed that the two lines were not identical, and it was only in 1925 that the mystery was solved, when the late Sir J. C. McLennan and Dr. Shrum showed that 5577 was due to oxygen, not in the condition of molecules as it exists at sea-level, but in the form of single atoms. These solitary atoms, McLennan concluded, came from the dissociation of ozone by ultra-violet radiation. For, although some wave-lengths in the ultra-violet band are thought to assist in the formation of ozone, others, notably those included in the Hartley band about 2550, break it up again.

The presence of 5577 in the auroral spectrum is, as pointed out by Simpson, another proof that the aurora only appears at high levels in the atmosphere, for it is only at about heights of 50 miles that conditions are favourable for the existence of atomic oxygen.

The prominence of the line, too, accounts for the predominant colour of the aurora, which generally begins as a greenish arch, and frequently keeps that colour throughout the display. The energy required to excite the oxygen atoms into emitting 5577 is comparatively low. Next in order of power requirements come the bright bands of nitrogen due to excited ordinary molecules; then come the violet lines at 3914 and 4278, which are emitted from nitrogen molecules that have been so disturbed that they have lost one electron, i.e. are singly ionised. It is significant that these latter lines are conspicuous in the kind of display described by Sir Walter Scott:

> And red and bright the streamers light
> Were dancing in the glowing north.

Very impressive are the red auroras, which owe their colour to the red oxygen line at 6300 A.U. In the folk-lore of the Western Isles the red cloud of light came from the blood shed in the fairy wars. One of these auroras, which appeared soon after the murder of Thomas à Becket in 1170, was thought to be the blood of the martyr going up to heaven, while, as late as 1854, a particularly vivid display came, in the minds of the Irish peasantry, from the blood that had recently drenched the ground at Balaclava. Of this type was the great aurora of January 25th, 1938; few who witnessed it will forget the magnificent red glow that flooded the sky at the climax of the display, and which owed its rich colour to the great enhancement of 6300 and its fellow red oxygen radiation at 6365.

At the present time much intensive research is being undertaken into the spectrum both of the aurora and of the night sky. The mutual behaviour of the two oxygen lines 5577 and 6300 is very interesting. In the spectrum of the night sky, 5577 weakens as dawn approaches, and in the rare auroras that are formed in the sunlit portion of the atmosphere it is four or five times weaker than the red 6300. The Norwegian observers attribute this effect to the action of nitrogen on ozone in the presence of sunlight.

The behaviour of the violet nitrogen lines is also very interesting. In the spectrum of the night sky these are much fainter than the green line of oxygen at 5577; in that of the ordinary aurora the three lines are of about the same intensity. In the spectrum of the very high auroras, which form in regions of what must be strong

radiation, the violet lines of ionised nitrogen are strong, and give their colour to these lofty displays, which wave mysterious curtains of grey-violet across the sky, veils of unsubstantial light hanging over the portals of what are, as yet, the unknown regions.

THE END

Postscript

In the preceding pages it has often been shown what opportunities the study of the realm of the air offers to the amateur. Many investigations can, of necessity, only be undertaken by trained observers in properly equipped observatories, but there are still many opportunities for the amateur to make observations which will not only afford him considerable interest, but may prove to be of real value to science. Interesting phenomena by no means confine themselves to the neighbourhood of stations of the Meteorological Office!

Observations of thunderstorms and associated phenomena, such as ball lightning, damage to houses, trees, radio sets, etc., are now organised under the British Thunderstorm Survey, which has headquarters at Langley Terrace, Oakes, Huddersfield.

Phenological studies (the relation between climate and plant and animal life) have their headquarters at the Royal Meteorological Society, 49 Cromwell Road, South Kensington, S.W.7.

Another interesting field of study for the amateur is the watch for optical phenomena, such as haloes, rainbows, mirages, etc. There is no organisation in connection with this, but careful and accurate accounts of interesting and unusual atmospheric happenings are always welcomed at the Meteorological Office, London. To make such accounts of real value they must be as concise as possible, and the time of the phenomenon must be given (in summer, care must be taken to make

it clear whether summer or Greenwich time is being used), together with as full details as possible of the weather at the time.

Naturally, a photograph, or simple, carefully made sketch, is a useful amplification of a written description. For clouds, panchromatic plates and yellow (for cirrus, some authorities prefer red) filters are useful. It seems also that some of the colour processes will give very satisfactory renderings of skies containing detached white clouds such as fine-weather cumulus.

Other phenomena cannot easily be photographed (haloes, for example), and sketches are better. In this connection some remarks, quoted by permission from the *Observer's Handbook* (H.M.S.O., 1934), by Mr. G. A. Clarke, of Aberdeen Observatory, may be of interest:

'On the appearance of any phenomenon the best method of procedure is to note down rapidly in a few pencil lines the general appearance thereof, and also to indicate on the horizon line (which should always be included in the sketch if possible) a few landmarks, the bearings of which are known. This will give the position of the phenomenon, and rough angular measurements can be made from these notes later on. Notes should also be made of the colours seen, especially if the rough sketch is intended to form the basis of a more finished coloured sketch.

'Haloes and other optical phenomena are very easily noted and sketched by observing their images in a black mirror (a piece of ordinary glass about 8 inches square, coated on the back with black varnish, makes an excellent mirror for the purpose). Rough angular measurements of the image can also be made, using the halo of 22° (radius) as a reference.'

Books to Read

The study of the atmosphere is a very live one, as is shown by the steady output of papers in every civilised country. So far as Britain is concerned, the bulk of new work is to be found in the publications of the Royal Society, the *Quarterly Journal* and *Memoirs* of the Royal Meteorological Society, and the *Geophysical Memoirs* and *Professional Notes* of the Meteorological Office. The M.O. also publishes the *Meteorological Magazine* (6*d.* monthly), which, in addition to articles and correspondence, contains monthly summaries of the weather and reports of the meetings of the Royal Meteorological Society.

Of books dealing with meteorology in general, the following may be recommended:

Short Course in Elementary Meteorology. W. Pick. (H.M.S.O., 2*s.* 6*d.*)

The Meteorological Glossary. (H.M.S.O., 4*s.* 6*d.*)

Weather Science for Everybody. D. Brunt. (Watts, 2*s.* 6*d.*)

The Weather Map. (H.M.S.O., 3*s.*)

CLIMATE

Climate and Weather. H. N. Dickson. (Home University Library, 2*s.* 6*d.*)

Article in *Encyclopædia Britannica.*

Recent work in the Polar regions on climate (p. 155) is to be found in *On the Top of the World* (Gollancz, 16*s*.), describing observations at the Soviet Drifting North Polar Station in 1937. No doubt, too, material will soon be available from the British Graham Land Expedition 1934–7.

SOUND

The World of Sound. Bragg. (G. Bell & Sons, 4*s*. 6*d*.)

Articles on individual subjects, e.g. 'Thunderstorms' in the present (14th) edition of the *Encyclopædia Britannica.*

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